PLATE I.

CONGLOMERATE SOIL ON SOUTHERN CANAL NEAR CARLSBAD, N. MEX., WHERE MUCH WATER IS LOST BY SEEPAGE.

From such sections as this large areas of land miles away from the canal may be ruined by seepage waters and alkali, attributed directly to the loss of water from the canal.

U. S. DEPARTMENT OF AGRICULTURE.

Report No. 64.

FIELD OPERATIONS OF THE DIVISION OF SOILS, 1899.

BY

MILTON WHITNEY,

CHIEF OF DIVISION OF SOILS,

WITH ACCOMPANYING PAPERS BY

THOMAS H. MEANS,   CLARENCE W. DORSEY,
FRANK D. GARDNER, FRANK K. CAMERON,
LYMAN J. BRIGGS.

PRINTED BY ACT OF CONGRESS.

To the Senate and House of Representatives:

I transmit herewith for the information of the Congress a communication from the Secretary of Agriculture, covering extensive field operations, consisting of soil surveys over various areas, aggregating 720,000 acres. In the opinion of the Secretary of Agriculture, this is the most important work of its kind ever undertaken.

WILLIAM McKINLEY.

EXECUTIVE MANSION, *February 5, 1900.*

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LETTER OF TRANSMITTAL.

Mr. President: I have the honor to transmit a report of this Department upon the field operations of the Division of Soils during the year 1899. It covers not only the most important work of this division, but, is, in my opinion, regarded in the light of the possible results of the information which has been secured thereby, the most important work of this character ever undertaken in any country. It consists of an introduction by Prof. Milton Whitney, the chief of the division, and special reports on the various lines of field work by the scientific assistants of that division, in cooperation in some instances with educational institutions in various parts of the country. The report covers, all together, a soil survey of an area of not less than 720,000 acres, scattered throughout the following regions: New Mexico, Utah, Colorado, and Connecticut. These accounts of soil surveys are followed by some valuable discussions on "the application of the theory of solutions to the study of soils," "some necessary modifications in method of mechanical analysis as applied to alkali soils," and " salts as influencing the rate of evaporation from soils."

It need hardly be said that it was found quite impossible to restrict this report within the limits of a hundred octavo pages, and consequently, under the operations of section 89, chapter 23, Volume XXVIII, of the Statutes at Large, 1895, the Secretary of Agriculture has no authority to secure the printing of more than 1,000 copies, a number which would be entirely inadequate to supply our exchanges, our agricultural colleges and experiment stations, and the divisional list of the Division of Soils, to say nothing of any miscellaneous demand. In this case, moreover, the Department, in my opinion, is bound to supply copies of the report to the very large number of persons who have rendered efficient aid to our surveyors in their field work.

Under these circumstances and in view of the great importance of the subject covered, I have the honor to recommend that it be transmitted to Congress, together with the maps, illustrations, and diagrams accompanying, to be printed by order of that body, and I further recommend that not less than 10,000 copies be printed for the use of this Department, in addition to such number as Congress may order for the use of its members.

I have the honor to remain, Mr. President, very respectfully,

James Wilson,
Secretary.

LETTER OF SUBMITTAL.

U. S. Department of Agriculture,
Division of Soils,
Washington, D. C., January 29, 1900.

Sir: I have the honor to present herewith a report on the field operations of the Division of Soils for 1899. This is, without doubt, the most important work that has been undertaken by the division since its organization. The report is illustrated by a number of photographs and diagrams showing the character of the country and the specific characteristics of the soil, and by accompanying maps showing the distribution of the soils, alkali, and seepage waters. That portion of the report prepared by Dr. Cameron relates to work undertaken in cooperation with the Division of Chemistry, and has been read and approved by Dr. Wiley. The soil work is of great interest and is very widespread in its application. A small edition would be entirely inadequate to supply the exchange list of the Department and the ordinary mailing list of this division, besides the very large number of persons who, having aided and cooperated with the division in its work, are entitled to a copy when published. I therefore have the honor to recommend that not less than 10,000 copies of this report be printed for the use of this Department.

Respectfully,

Milton Whitney.
Chief of Division.

Hon. James Wilson,
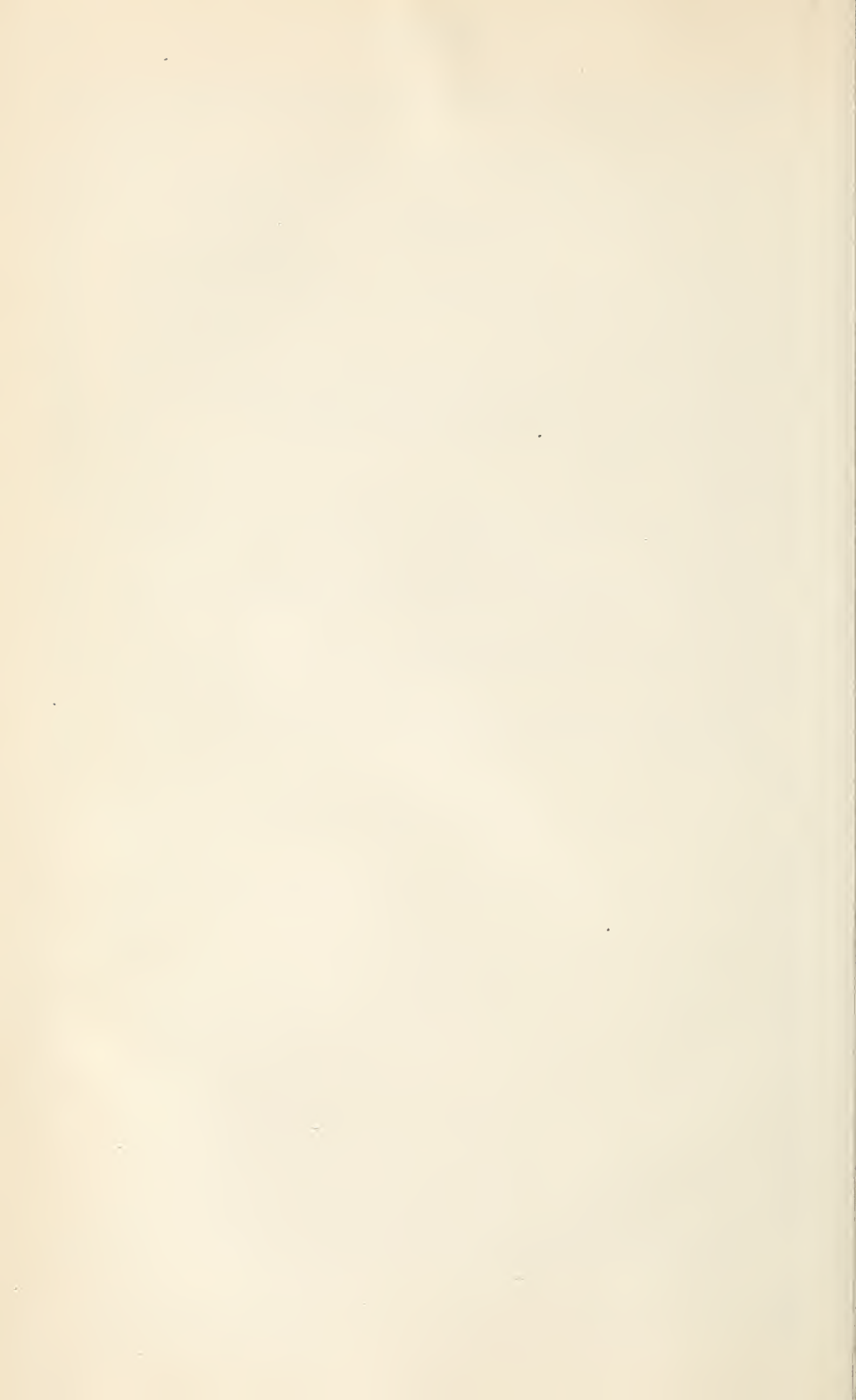*Secretary of Agriculture.*

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[In pocket on last cover.]

FIELD OPERATIONS OF THE DIVISION OF SOILS IN 1899.

By **MILTON WHITNEY**, Chief of Division.

PROGRESS AND COST OF THE SOIL SURVEY.

During the season of 1899 three well-organized parties were in the field for from six to eight months each, equipped according to the most modern methods for surveying, investigation, and mapping the soils of several important agricultural districts. Eleven hundred and twenty-five square miles, or about 720,000 acres, have been surveyed and mapped on a scale of 1 inch to the mile. The following table shows the areas which have been surveyed, the rate per day, and the actual cost of the field work per square mile:

	Area.	Rate per day.	Cost per square mile.
	Square miles.	*Square miles.*	
Cecil County, Md	375	5	$1.70
Connecticut Valley	400	4.5	2.00
Salt Lake Valley, Utah	250	2	a 6.00
Pecos Valley, New Mexico	100	1.1	12.00
Total	1,125		

a The actual cost of the work to the Division of Soils was $4 per square mile, the Utah Experiment Station cooperating and paying the equivalent of $2 per square mile.

The difference in the cost of the work is due to the more complex problems presented in the arid regions of the West, as will be explained, as well as to the greater distance from Washington and the consequent greater cost of transportation. The cost per square mile given in the table includes the salaries of the men while actually in the field, together with their transportation and subsistence expenses. Taking into account the annual salaries of the men assigned to the soil survey, together with all expenses directly chargeable to the work in the field, the amount expended during the calendar year 1899 for such work amounted to 27.8 per cent of the total appropriation for the Division of Soils. The laboratories, contributing largely to the efficiency and support of the soil surveys, consumed 22.5 per cent of the total appropriation; the administrative expenses—including rent of building, express, gas, and the fitting up of an additional laboratory room— amounted to 40.5 per cent of the total appropriation.

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For administrative purposes in the Division of Soils the United States has been divided into the eastern and western districts, with the Mississippi River as the dividing line. Mr. C. W. Dorsey has general charge of the soil survey of the eastern district, and Mr. Thos. H. Means of the western district. In the western district the work has so far been confined to irrigation districts, and has included, besides the mapping of the soils, the investigation and mapping of the alkali conditions and of the depth to standing water. Such maps, showing the exact distribution and condition of the soil, serve as a basis for the improvement or reclamation of alkali lands by underdrainage or by other means for removing the excessive accumulation of alkali and seepage waters. They also show the source of possible future damage, and by their aid suitable preventive measures can be taken to provide against such losses as have occurred in the past.

In localities where sodium carbonate or black alkali prevails a separate map is made, showing the distribution and relative intensity of this substance.

The areas which have been surveyed this year are not at all simple in their conditions, and represent perhaps as great a variety of soils and soil conditions as will ever be encountered in a season's work. As a rule, the soils of the West are more uniform over small areas than they are in the Atlantic Coast States, but on account of the greater number of conditions to be taken under consideration and investigated, in the surveying and mapping, and the necessarily more complex field methods, the work is much slower.

The expense of the work in Cecil County, Md., and in the Connecticut Valley averages less than $2 per square mile, including the salaries of the men while in the field and the transportation and subsistence expenses. This is considered very satisfactory. The parties consisted in each case of two men working together, each party having a horse and wagon.

The relatively small area per day covered in the Pecos Valley, New Mexico, and the apparently excessive cost ($12 per square mile) is accounted for by the newness of the work, the fact that two experienced men were assigned to this work—for their mutual training and for the final perfecting of the methods—and to the further fact that considerable detail work was done in the study of the conditions and methods to be used under such conditions—necessary work which will not have to be done again.

The expenses of the work in Salt Lake Valley, Utah ($6 per square mile), are considered fairly satisfactory, although it will doubtless be possible to materially increase the rate per day, and thus lessen the cost per square mile as the men become better acquainted with the methods of surveying and with the causes and conditions of the alkali soils. With the experience of this season such an area as this could probably be surveyed now at a cost of about $4 per square mile.

It must be remembered that the estimation of the cost of such work in new localities is a mere approximation, as the expense depends largely upon the complexity of the conditions in the locality to be surveyed. In each of these districts in the West the field parties consisted of two men, with a horse and wagon for carrying the field equipment, without a camping outfit, as the work done was in rather closely settled districts.

It has been the intention to have an experienced man in charge of each field party, with a student assistant or an intelligent laborer to assist in the work. So far as possible advantage is taken of these opportunities to train men for the more responsible positions devolving upon directors of field parties. Such educational work is a very essential and important part of the work of the division, as it is impossible to obtain men already trained and fitted for this field work.

COOPERATION WITH STATE ORGANIZATIONS.

Wherever possible it has been the policy of the division to work in close cooperation with the State experiment stations, the State geological surveys, boards of agriculture, or other local institutions. This cooperation, so far as it has been carried, has proved mutually satisfactory and beneficial to the local institutions and to this division. In a general way it relieves the local institutions of all responsibility of the direction of the work and the preparation of the material, while the expense to them is very much less in every case than if they had to employ competent soil experts, even if such experts could be obtained, which is questionable. On the other hand, this cooperation enables the Division of Soils to very materially widen its sphere of field work, and gives the division a desirable connection with local institutions, in touch with the people actually interested in the work.

Owing to the difference in the character of the work in the Eastern and Western districts the basis of the cooperation with State institutions has been essentially different. The arrangements under which the work has been done during the present season may be briefly stated.

The soil survey of the Connecticut Valley was carried on by the Division of Soils, independently of any other organization, under the authority of Congress to investigate and map the tobacco soils of the United States. This work was in charge of Mr. C. W. Dorsey, with Mr. J. A. Bonsteel, of the Johns Hopkins University, as temporary assistant. A detailed soil map, with accompanying text describing the different soils, is given in the latter part of this bulletin.

Under authority from the Secretary of Agriculture an agreement was entered into with the Maryland geological survey, Dr. William B. Clark, director, to survey and map the soils of Maryland at the rate of one county each season, which is the present rate at which the topographic base maps and the geological data are being prepared. Under the terms of this agreement the Division of Soils assumes the

entire responsibility for the details of the soil survey, together with the preparation of the manuscript map, with a brief description of the soils. This material is turned over to the State survey, the Department reserving the prior right of publication, to be published with such additional data as they may wish to include in their final report. The publication of the map by the Division of Soils, with brief notes as to the soil classification, is not expected to conflict in any way with the more elaborate State publication for local distribution. Under the terms of the agreement the Maryland Geological Survey pays the traveling and subsistence expenses of the field party. This amounted in the present case to about $400, or approximately $1 per square mile. The area selected by the director of the State survey was Cecil County. While the soil survey has been completed and the manuscript map prepared, the publication will be delayed a year, awaiting the engraving and publication of the topographic base sheet, which has just been completed in manuscript.

The soil survey of the Pecos Valley, New Mexico, was carried on by Thomas H. Means and Frank D. Gardner, of this division. The entire expense was paid by the Division of Soils, and there was no official cooperation with any other organization. The New Mexico Experiment Station, however, authorized Prof. J. D. Tinsley to accompany the field party for the purpose of studying our methods. Professor Tinsley spent about a month helping with the work in the district around Roswell.

The work in Utah was done in cooperation with the Utah Experiment Station, Prof. Luther Foster, director. The terms of the cooperation were that the Division of Soils would send an expert to take charge of a field party, pay his salary, traveling and subsistence expenses, and be responsible for the preparation of maps and reports which would treat fully of the conditions of the area. The Utah Experiment Station would furnish an assistant and pay his salary and traveling and subsistence expenses while in the field. The expense to the experiment station amounted to about $2 per square mile.

In this alkali work, unlike the soil work in the eastern district, the reports have to treat very fully of all the conditions, and the same report will therefore serve for and be credited to the Division of Soils and to the Utah Experiment Station.

The director of the Utah Experiment Station designated Mr. John Stewart as an assistant in the Utah work, Mr. Frank D. Gardner having direct charge of the field party. The results of the field work are briefly referred to in this paper and are set forth in detail in the accompanying papers and maps.

In the progress of the field work this year, and particularly in the review of the work in the preparation of the reports and maps, many valuable modifications have been suggested in our methods which it is believed will greatly simplify the work and increase the efficiency

of the field parties. One feature which has been brought out clearly is the fact that the field methods are now practically independent of the laboratory methods. The soils and alkali salts are classified and mapped in the field. The maps themselves are actually prepared in the field in such form that they can be turned over to the lithographer after suitable titles and legends are prepared. This refers to the soil, the alkali, the black alkali, and the underground water maps. Much of the laborious work of calculating the actual salt content has been saved, as limiting values only are shown upon the map, and it is hardly considered advisable to publish the figures of actual salt determinations in tables which few, if any, would read.

The laboratory work connected with the survey has likewise been reduced to a minimum. The chemical and physical laboratories are used now simply to explain the character of the soils which have formed the basis of the classification. For example, the physical differences between the Hartford sandy loam and the Connecticut meadows are clearly brought out in the mechanical analyses. On the other hand, the differences between the Pecos gypsum soil and the Pecos sandy loam are apparent not only from the mechanical analysis, but also through the chemical analysis. These conditions, however, are so marked in each case and so apparent that the soil areas can be accurately mapped, even without the results of the physical and chemical examinations. This matter of the field methods will be referred to more at length on a subsequent page.

The alkali and underground water maps show the conditions at the time of the survey. At different seasons of the year and especially under different weather conditions the soil conditions may be somewhat different; but as the examinations are usually made during the growing season the conditions shown may be taken to represent fairly well the actual conditions of growth.

OPERATIONS IN THE PECOS VALLEY, NEW MEXICO.

Reports have come in to this Department from time to time for several years from the Pecos Valley of root-rot disease affecting fruit trees, grapevines, sugar beets, and alfalfa—the trees and vines much more seriously than the other crops. Truck crops seem to have largely failed in the valley, while the yield from alfalfa, which seems to be the crop best adapted to the conditions there, is only about 5 tons to the acre in 4 cuttings. In Montana it is from 6 to 7 tons in 3 cuttings.

In view of these serious reports, the importance of the locality, and the expressed willingness of the people to benefit by the results of the investigations, it was decided to send an expedition to investigate and map the soils and soil conditions of a portion of the valley. Accordingly, Thomas H. Means and Frank D. Gardner, of this division, were sent out and spent two months at Carlsbad and one month at Roswell. I personally inspected the work during the progress of the investigations. The detailed account of this work is given in an accompanying

paper, and is illustrated by a series of maps, diagrams, and photographs.

It was found in the Carlsbad area that fruit, truck, and grapes were almost entire failures; that the sugar beets and alfalfa gave relatively small yields and were affected with root-rot over certain areas. There are many abandoned farms and large areas over which the conditions generally are not satisfactory.

One reason that fruit has not been successful is the liability of the occurrence of late spring frosts which destroy the buds after they have started. The root-rot disease, which has been so destructive in the valley, is unquestionably largely due to the condition of the irrigation water during part of the year and over some sections of the valley. The salt content of the water is so high that it is near the limit of endurance for crops. The occurrence of gypsum soils and of seepage waters also accounts for much of the trouble. These matters will be briefly summarized here.

In regard to the natural conditions which have had to be contended with, it may be well to state that the settlers were not well prepared to meet these new and untried conditions. In settling the valley the land company attracted a large number of settlers from abroad as well as from various parts of this country. Many of the persons locating in the valley were entirely unacquainted with the exact conditions prevailing in the Pecos Valley, and, indeed, unacquainted with the methods of irrigation in general. The settlers paid the company so much an acre for the use of the water and unfortunately felt that the more they used the more of value they were getting from the company. From these various reasons there was undoubtedly some bad management which resulted occasionally not only in the financial ruin of the owner, but seriously damaged by seepage waters his own or his neighbor's land as a result of over-irrigation.

At the present time much of the ownership of the land is vested in the water company and rented to irresponsible Mexican settlers who move from place to place and have not much interest in using the necessary means for preventing damage to the land, and who are quite willing to move if crop failures result from their own mismanagement or from any other cause. This social condition must be taken into account in any plan for the improvement and reclamation of the lands. A Mexican settler is not likely to invest money in underdrainage or in any other method of preserving or reclaiming the land and, owing to the uncertain tenure of these tenants, the company naturally hesitates before putting in any expensive improvement of this kind. The conditions, therefore, are not as satisfactory as might be wished for the most efficient work in the reclamation and general improvement of the lands.

Next to the ownership of the land and the labor questions, the most important cause of the trouble in the larger portion of the Pecos Valley

is the high salt content of the irrigation water, especially in certain seasons.

At Roswell the principal water supply contains about 76 parts of soluble matter in 100,000 parts of water. At Hagerman this is increased to about 200 parts; at Carlsbad to 240 parts; at Florence to 280 parts; Red Bluff, 316 parts; at Pecos City, Tex., to 400 parts; and below Pecos City to over 500 parts. Five hundred parts of soluble matter in 100,000 parts of water, when added to the soils of the Pecos Valley, may be taken as the extreme limit of endurance for plants, while 250 or 300 parts mark the danger point at which the results of the use of the water are very uncertain.

It should be stated that only about 50 per cent of the solid matter contained in the Pecos waters is harmful, and the above figures should be divided by two to obtain the real concentration so far as really harmful salts are concerned. The inert soluble matter consists of gypsum and carbonate of lime held in solution through the influence of other more soluble salts. These substances crystallize out on the evaporation of the water and are not readily dissolved thereafter. These are, therefore, not liable to accumulate in the soil in a soluble form, and for this reason due allowance should be made for the proportion they make of the total amount of soluble matter in the water.

The limit of endurance for most cultivated plants in a water solution is about 1 per cent or 1,000 parts of the readily soluble salts in 100,000 parts of water, but it must be remembered that in field culture the water is applied to soils already containing more or less of these salts, and also that evaporation and consequent concentration immediately set in after the application of water. It was found at Carlsbad that about 300 parts of soluble matter per 100,000 parts of water marked the extreme limit of safety of the use of water at that place.

In the use of water for irrigation purposes so close to the limit of plant endurance, as occasionally occurs at Carlsbad, there are certain precautions which can and should be taken to insure the safety of the crops and the permanence of the fertility of the soil.

In the arid climate of New Mexico where evaporation is so excessive the actual amount of evaporation becomes an important factor in determining the condition of the water. It is stated that the evaporation at Carlsbad amounts to about 10 feet in depth in the course of a year. Evidently, therefore, the deeper the reservoir in proportion to its area the more economical it is as regards the condition of the water. The same bulk of water in a reservoir 20 feet deep with perpendicular sides would lose just half as much by evaporation as if the reservoir were 10 feet deep and the surface area twice as great. There are, of course, engineering conditions which have to be considered in the construction of such reservoirs.

As the absolute evaporation from an equal area of water surface is just about the same where the reservoir is full or nearly empty, the

water in a partially filled reservoir becomes more concentrated as a result of this evaporation than where the reservoir is full. So far as the condition of the water is concerned, therefore, it is advisable to keep the storage reservoir well filled. In cleaning or repairing the reservoir the water is occasionally drawn off in the fall or winter at the beginning of the dry season when work is slack and the danger of floods is at a minimum. If, however, the water has to stand for a long time in this low stage the evaporation has much more effect upon the concentration than if the surface had not been lowered. If the usual rains are delayed and this water has to be used to start the crop, it may be so concentrated as to be unfit or unsafe for use. This is a matter which requires the careful consideration of the engineer in charge.

In a large drainage area, such as is found in the upper part of the Pecos Valley, the alkali salts usually come to the surface and form a crust over extensive areas during the dry season. With the first floods much of this salt is carried down into the river and, as a consequence, the first waters of the spring floods at Carlsbad contain a dangerously high salt content. If the reservoirs have been low and the waters are already concentrated the first flood waters may make the waters of the reservoirs unfit for use until further rains and floods have come down. Where possible, under conditions of this kind, it would be advisable to divert the first flood waters and not allow them to enter the reservoirs at all. In many places, of course, this would be an engineering feat of so much difficulty and expense that it could not be considered, but where it is possible, under conditions such as prevail at Carlsbad, it would be very desirable.

With the irrigation water so near the limit of endurance as sometimes prevails in the Pecos Valley it would be desirable to have a record kept and daily or weekly notifications sent to the users of the water of the actual conditions as regards the salt content. With one of the electrical instruments in use by the Division of Soils, the total salt content of the water could be determined in a few moments, at the reservoir, in a flume, in the canal, or in the river before it enters the reservoir. The total salt content thus determined, representing the condition of the water, should be communicated by telephone or otherwise to the principal landowners and users for their information and guidance.

It may be perfectly safe to use water of a relatively high salt content on certain well-drained soils when it would be ruinous to allow the same water to be used on a poorly-drained soil containing a high salt content. Furthermore, the previous condition of the soil and the kind and age of the plant has much to do with the safety in applying water which approaches the limit of crop endurance.

The soil map accompanying the report of Messrs. Means and Gardner shows that there is no excess of alkali in the Pecos sandy loam,

which includes most of the cultivated land in the valley, except in a few draws and low places. With this map and the alkali map it should be possible to determine the limit of the salt content of the water which it would be safe to use on any locality given on the map, as well as for the different plants at their different stages of development. This is a matter which should receive the thoughtful attention and consideration of all who are interested in the development of agriculture in such a community as this.

At several points along the Southern Canal, in the Carlsbad district, the canal bank is thrown up on the lower side and the water is allowed to rise and flow over an area of from a quarter of an acre to several acres in extent on the upper side, forming a small lake. This is avowedly done to save the labor of making embankments and for increased storage purposes. It is an exceedingly pernicious thing to allow, however, for two reasons; namely, it presents a relatively large surface for evaporation and in this way increases the concentration of the solution to a marked extent, and the seepage from the canal is very greatly increased by allowing the water to spread out over such an area. It is very common to find small ponds or lakes some distance from the canal, formed and supplied by the seepage waters from the canal. The ordinary seepage from the Southern Canal probably accounts for a large amount of the trouble from seepage waters in the Carlsbad district. This trouble is confined largely to the conglomerate and gypsum areas, but it is unquestionably felt to quite a marked extent in other soils. It was found that in one place in the gypsum area the canal lost about 20 per cent its volume in a distance of about $1\frac{1}{4}$ miles. This is going on all the time the canal is flowing. There is no question but what the excessive subirrigation of the gypsum lands, and probably of the other subirrigated lands shown upon the underground water map, is due to the seepage from the canal and its laterals, rather than from overirrigation by the farmers. This matter of the storage ponds along the canal, which has just been referred to, is responsible for a great deal of this unnecessary injury.

In Bulletin No. 14 of this Division, on the Alkali Soils of the Yellowstone Valley, attention was called to the fact that lands receiving the most careful treatment by the people living on them might be ruined by seepage waters and alkali caused by the seepage from canals or by the improper use of water on a neighboring place, perhaps several miles distant. Many instances of this kind have been seen, not only in the Yellowstone Valley, but in the Pecos Valley, which is now under consideration. It seems to me that this is a matter for the States or for Congress to take up with a view that provision be made by statute that reasonable care be taken to protect ditches and canals from undue loss of seepage waters and to provide that reasonable care be exercised in the use of irrigation waters. Provision should be made for the recovery of damages through civil suits in case of injury to

property through such sources.   It is quite as important for the States to exercise such police power in protecting a man's property from destruction by seepage waters from a canal or from injury by the excessive use of irrigation water by a neighbor, as to protect his property from depredations of any other kind.

It is of the utmost importance, in a locality similar to the Carlsbad district, where the seepage from the canal is seen to be doing so much injury, that the canal company be required to provide against this loss of water through seepage, and so protect the surrounding country from the dangerous effects of the seepage waters which are seen to occur.   Particularly is this necessary where the canal goes through a loose gravelly area or through the gypsum soils, which have the peculiar property of transmitting seepage waters so readily and for such long distances.   There are various ways in which such protection can be afforded, ways that are voluntarily used by the water companies in districts where water is scarce.   It is neither right nor reasonable to permit the wide destruction of property values simply because water is plentiful and is in itself cheap.   Where the cause of the trouble is shown so clearly as in the Carlsbad district there should be no hesitation in providing adequate protection to the community.

The maps show that with few exceptions the soils of the Carlsbad district are free from excessive quantities of alkali.   With the knowledge gained through this investigation of the dangers inherent in the relatively large salt content of the waters, to the danger from seepage from the canals and from overirrigation, and the nature of the soil, it should be possible to provide that such careful methods be used that certain lines of agriculture can be successfully carried on under the prevailing conditions.

There are other questions which determine to a considerable extent the economic value of crops in this area.   For example, the soils of the valley contain a large amount (from 10 to 20 per cent) of carbonate of lime.   It is the experience in certain localities that apple trees will not grow well with a subsoil containing so much as 20 per cent of lime. In the matter of sugar beets also, where the water used contains an undue amount of salt, a large proportion of the sugar fails to crystallize, and is lost.

There are other questions quite as important as these to be considered, but they belong more particularly to some of the other divisions of the Department of Agriculture.

One thing should be said in connection with the Carlsbad area, which seems rather anomalous in view of the statements of other investigators, namely, that with a water supply so near the limit of crop endurance as this becomes at times and in those areas in which there is already a large accumulation of salts, that economy in the use of irrigation water, which is generally recommended in alkali regions, is one of the worst methods which can be practiced.   Where the soil contains a relatively large amount of salt and but little water con-

taining much salt is frequently applied, the ordinary evaporation will increase the salt content of the soil to such an extent that crops can no longer survive; whereas if adequate drainage is provided, and a large amount of water is used, the excess of salt resulting from the evaporation of previous applications of water, may be removed, and the soil moisture be maintained at nearly the same concentration as the water supply. It is advisable, therefore, over certain localities, at least in the Carlsbad district, to provide underdrainage where necessary, and then use relatively large applications of water, rather than frequent small applications. If the drainage is adequate, it may be that an occasional flooding in the winter would leave the land in good condition for the coming season, and that during the season frequent small applications can then be used to advantage.

A portion of the town of Carlsbad lies directly under one of the conglomerate banks. The seepage through this from the canal has raised the water surface to within 2 or 3 feet of the surface of the ground. As a consequence of this the shade trees have suffered, and many of them have died. An attempt was made to improve the conditions by stopping the irrigation altogether. This made matters worse. The water in the soil concentrated so rapidly and to such an extent that the trees began dying off quite rapidly until, on the advice of Professor Skeats, irrigation was once more resumed, and the conditions were ameliorated. The irrigation in this case should be supplemented by underdrainage, which would not only lower the water level in the soil and secure better aeration, but it would secure better control of the salt content of the soil by occasional flooding.

Some observations by Mr. Gardner on these soils are interesting and instructive. A series of tubes was inserted into the soil down to the water level, so that the fluctuations of the water level could be observed with a rod or float. In addition to this, a series of electrodes was put into the soil at intervals 2 or 3 inches apart down to standing water. It was possible by these means to watch the effect of irrigation on the soil moisture. Before irrigation the level of standing water was 3 feet. Within thirty minutes after the irrigation water had reached the place both the tubes and electrodes showed the level of standing water to have risen to the surface of the ground. The water was held on for some time after the complete saturation had been effected, and after it was stopped it took several days for the natural drainage to restore the normal conditions and for the water level to sink to its former level. Such conditions must be unhealthy for crops, and if the excessive flooding and complete saturation is necessary to remove accumulated salts, artificial drainage should be introduced to quickly remove the excess of water used, as well as to lower the level of standing water in the soil.

The maps show that in the Roswell district extensive areas of land are already ruined by seepage waters and by alkali. This has unques- tionably come from the seepage from the canals and from overirriga- tion. The area is small and seems adapted to intensive farming, and

there is no reason why at comparatively small expense these lands should not be underdrained and the present trouble entirely removed. The water supply is so good that with adequate drainage provided, there is no question about the ease with which the damaged land could be reclaimed.

The conditions are so clearly presented in the report and accompanying maps and the remedies are so obvious that further comment in this place is unnecessary. The investigations certainly point to a most encouraging prospect for success in the Roswell district.

Pecos City and Barstow are approximately 80 miles south of Carlsbad. The Pecos River, supplying these places with irrigation water, gathers the unused, waste, and seepage waters from the Roswell, Hagerman, and Carlsbad irrigated areas, and the salt content of the water is so great as to be beyond the limit of endurance for most plants during the greater part of the time.

Nothing can be said, no advice can be given for the successful irrigation of lands where the water supply has so large a salt content as at these places. It is just possible that at certain times of the year and in certain states of the water the water supply may be pure enough for successful irrigation, and that by the construction of large storage reservoirs and the diversion of the water when the salt content reaches a certain maximum a small irrigated district could be maintained; but these are questions which would require a detailed investigation extending over a number of years. It would be advisable to have records made of the conditions of the water from day to day for at least two or three years, and not rely upon the single determinations which have been made, although these are supported by the experience of the past years in the practical irrigation of the lands.

Mention has already been made of the occurrence of the root-rot disease in the Carlsbad district. So far as can be determined with a single season's observations and without the necessary investigations of the vegetable pathologist, it would seem that the character of the soil with the high content of carbonate of lime, which is known to be prejudicial to certain crops—especially apple trees—and with the water supply so charged with salts as to be near the limit of endurance for crops, the vitality of the crops would be so low that they would become peculiarly subject to diseases which in a more vigorous condition they could readily resist. This is a matter, however, for the Division of Vegetable Physiology and Pathology, and I consider that these records and maps would form a very valuable basis from which they could work out economic problems in vegetable physiology and pathology which others have tried for years to study in the confined limits and under the artificial conditions of pot culture. It is a line of investigation which is well worthy of being followed out, as it is of the utmost economic importance not only in this, but in other irrigated districts of the West.

SALT LAKE VALLEY.

The Salt Lake Valley is the oldest of the modern irrigation districts and has been noted for the high state of cultivation of the lands by the Mormons. During recent years, however, complaints have been made of the damage by alkali and seepage waters of the lower levels, which were formerly the most productive soils of the valley. The tendency has been for the settlers to move farther and farther back onto the higher benches.

The work of the field party was confined to that portion of the valley west of the Jordan River and extending to the Great Salt Lake and to the Oquirrha Mountains. This area comprises approximately 250 square miles, or about 160,000 acres. Of this large area only 40 square miles, or approximately 25,000 acres, are at present under irrigation, and 50 square miles, or 32,000 acres, are all that have ever been under successful irrigation. About 90 square miles, or approximately 58,000 acres, are above the canals and are at present not available for irrigation. There are about 125 square miles, or approximately 80,000 acres, in a vast level stretch of country west and north of Salt Lake City, extending to the Great Salt Lake. Of this it has been estimated that about 90 square miles, or approximately 58,000 acres, are capable of improvement through underdrainage or irrigation. The remaining 35 square miles of this area are in flats of heavy clay soil of low elevation, filled with alkali, which it would be inadvisable or impossible to underdrain.

The water supply of the Jordan River is reasonably pure and is well suited for irrigation purposes. The most recent canals were taken out near the Jordan Narrows and have nearly the same composition as the Utah Lake. Farther down the river gathers some alkali from seepage waters, but it also gains a considerable quantity of fresh water from mountain streams, so that there is considerable variation in the salt content in different parts of its course. There seems to be an ample water supply to irrigate all the land which could be brought under the ditch, but on account of the high salt content of the soil irrigation has never been successfully practiced on the 125 square miles of nearly level land west and north of Salt Lake City.

Of the 50 square miles which have been under the ditch and successfully cultivated, about 10 square miles, or one-fifth of the whole area, have been ruined by seepage and alkali salts from the higher levels. This abandoned land is now wet and swampy, and about 1,000 acres are actually covered by large lakes which have been formed by the seepage from canals and irrigated lands. These abandoned lands were originally the most fertile portion of the area, and being for the most part nearer the city had a value probably of not far from $80 to $100 per acre. This damage is gradually extending back toward the bench lands. It could readily be stopped with more care in the construction of the canals and in the use of water supplemented by thorough drainage.

There is a scheme on foot at the present time to construct a high-level canal, taken out from the Jordan Narrows, to be supplied by hydraulic pumps, which would bring under the ditch a large portion of the 90 square miles at present above the irrigating canal. This would increase the danger, however, to the lands at present under irrigation, and steps should be taken to protect these lands and prevent the encroachment of the seepage waters and alkali on the lower levels. This is a matter which could easily be accomplished at a moderate cost. It would necessitate more careful work in the construction of the canals, to prevent seepage, and adequate drainage on the lower levels.

The greatest problem, however, in the valley at the present time is the reclamation of about 100 square miles of the land lying adjacent to and west of Salt Lake City. There seems to be no question about the feasibility of the engineering problem in underdrainage there, or about the efficiency of underdrainage in the reclamation of these lands with the water supply so good and so abundant as it is. The cost of underdrainage would be no greater than for similar lands in the States of New York, Ohio, or Illinois; while the value of these lands, being so near Salt Lake City, would certainly be as great as in those States where underdrainage has been so extensively carried on and is considered so essential in the cultivation of the land and the maintenance of its fertility. There would thus seem to be a fine opening as a commercial enterprise in the development of these lands through underdrainage.

There is a mean average fall from the ridge running in a northwesterly direction from Salt Lake City of about 2 feet to the mile down to the lake. This would be ample for the main drainage canals, as the irrigation canals are frequently built with about half this fall per mile. The drainage of these lands would be rendered comparatively easy through the numerous draws already existing, which are from 6 to 8 feet below the general level of the surface into which the drains could empty. Good tile clay is abundant in the vicinity and tile could be made and delivered to the farmer at a reasonable cost.

Over such an extensive area as this the drainage systems should be well devised and should be a community affair rather than constructed through individual efforts. The cost of underdraining these lands with tile is estimated at from $10 to $20 per acre, depending upon the texture of the soil and the distance apart of the drains. These lands at present have no value or only a mere nominal value for grazing purposes. The irrigated lands of the locality are worth from $60 to $80 per acre. If these lands adjacent to Salt Lake City were reclaimed through underdrainage they would be worth certainly from $60 to $80 per acre, and much more than this if held as suburban property. This reclamation work should be carried on as a community enterprise, aided perhaps by county or State credit, as has been done in many sections of the country where similar enterprises are undertaken.

These are the great problems presented in the Salt Lake Valley, problems presented very clearly in the report prepared by Messrs. Gardner and Stewart. From the evidence there presented, and especially from the maps, the actual conditions in the valley may be clearly understood. The soil map shows the distribution of the different types of soil, the Jordan sandy loam forming by far the greatest extent of valuable land. This soil is not originally very alkaline and it is easily drained and improved. The Jordan loam is rather more difficult to deal with, while the Jordan clays, from their slight elevation and the impervious nature of their material and the large accumulation of salts in them, would present great difficulties and would perhaps prove impossible of reclamation.

Where this Jordan clay occurs at a reasonable distance from the surface, however, it undoubtedly adds strength to the lands. Where it comes too near the surface it is an element of danger, as it impedes the drainage of the soil. The relation of these soils to drainage, seepage waters, and alkali should be very carefully studied by the farmer.

The alkali maps and the underground water map show very clearly the conditions prevailing over the whole district. Attention should be particularly directed to the very large accumulation of alkali in some of the areas north of the Twelfth street road. Also the remarkable accumulation of sodium carbonate or black alkali should be considered. This sodium carbonate occurs in places to as great an extent as 3 per cent in the surface foot of soil, while the composition of the crust which forms over the surface indicates at least a possibility that it may be sufficiently pure for commercial purposes.

One interesting thing in connection with this area is that calcium chlorid has been found to occur in very large proportions in some of these crusts, and strontium is also present in appreciable amounts. No attempt was made to investigate the economic importance of these salts, but the indications are that it would be worth while to look into the matter further from an economic point of view.

The investigation of the hardpan forming on the shores of Great Salt Lake is interesting and valuable. It seems to me that the whole matter of the occurrence and formation of hardpan in soils is very nearly solved, and that before very long this troublesome question in agricultural practice will be fully understood. The observations of Messrs. Gardner and Stewart and the paper by Dr. Cameron have contributed important facts and suggestions toward the solution of this problem.

THE CONNECTICUT VALLEY.

The report of Mr. Dorsey on the soil survey of the Connecticut Valley, with the accompanying map, presents so clearly the conditions prevailing there that little comment is necessary at this place. Furthermore, it is but the basis of a very extensive and comprehensive

investigation by this division, authorized by Congress in the present appropriation bill.

The map shows the distribution of the soils of the valley, which are described with all necessary detail in the accompanying report. The sides of the valley are formed for the most part from the glacial deposits of Triassic sandstone, and in the northern part of diabase. The soils of the valley proper are sediments which have been washed over and assorted in the great lake which is supposed to have covered this area in prehistoric times. Some of the soils occur in well-defined terraces, which formed the shores of the old lake, or which were formed subsequently by the river and streams. Over much of the area, however, these terraces are ill-defined or entirely lacking, and, from the differences in elevation of the same soil formation in different parts of the valley, there are even evidences to disprove the terrace theory of the physiography of the country. Certain it is, however, that the soils were laid down by water, and that in so doing they were sorted out in various grades of fineness. Beginning with the present meadows, which are composed of very fine sand and silt, the Podunk region is in a well-defined terrace elevated about 20 feet above the meadows and is composed of one grade coarser material, but still so fine as to be just distinguishable by the eye.

The Hartford loam, forming the principal tobacco soil, in extent at any rate, is a grade coarser than this, while the Windsor loam, believed to be the original bottom of the old lake in its shallowest portion, is very coarse sand, containing some gravel. These Windsor sands produce the finest wrapper leaf when the season is favorable, but a good crop is secured only one or two years out of five.

As Mr. Dorsey points out in his report, the one great trouble with the Connecticut tobacco is that it does not conform to the present requirements of the cigar trade. The leaves are too large, the veins are too large, the base of the leaf is too glossy and lacks texture and style, while the color of the leaf is far from uniform. An attempt is soon to be made to secure a radical change in the type of the leaf by close planting, allowing many more leaves to the stalk, by very rapid growth, by shading, and possibly by irrigation. These experiments with the Connecticut tobacco will be undertaken in the hope of producing a leaf approaching more nearly the Sumatra type of wrappers, this type being generally accepted in this country as the standard for cigar wrappers.

With the intensive cultivation that this will require, it is quite possible that these Windsor sands may be looked to for the finest wrapper leaf. I am of the opinion that even with the present style of leaf it would pay to irrigate these lands where this could be done easily and cheaply, in order to secure a crop four times out of five at least where now it is only possible to obtain one or two crops out of five.

The Hartford loam is decidedly a safer soil and can be relied upon to produce a fairly good crop of the Havana seed leaf variety each year.

This tobacco has a peculiar "seedy" taste which it is desired to get rid of and it is possible that this may be accomplished through selection and breeding, if not by radical departures from the present methods of cultivation and fermentation.

Such questions as these will form the basis of an extensive line of investigations already outlined, requiring several years of systematic work.

CECIL COUNTY, MD.

The soil work for the Cecil County sheet has been completed during the present season, but the topographic base map has not yet been engraved and will not be available for publication before the fall of 1900. Photographs of the pencil copies were kindly furnished by the United States Geological Survey for the actual field work and transfers will be obtained as soon as the plates are engraved. The soil map will be published in cooperation with the Maryland geological survey.

LABORATORY WORK.

The paper by Dr. F. K. Cameron, soil chemist of the division, cooperating with the Division of Chemistry, together with the one by Mr. Lyman J. Briggs, physicist of this division, shows some important advancements made in the methods of soil investigations, which have very materially increased the efficiency of our field parties and have made them quite independent now of the laboratories, except so far as the laboratories will be used to investigate and explain the basis upon which the soils have been classified in the field in order to show as fully as possible the physical and chemical peculiarities of the different soils.

The electrical methods of determining the moisture and salt content of soils are based upon the conception of the soil moisture as being a solution of a mixture of more or less difficultly soluble substances. Dr. Cameron has carried this further in the application of the modern theories of solution to the study of some of the most difficult soil problems. As a result of this, new methods of field analysis of mineral substances have been devised, and the occurrence of certain mineral substances in the alkali soils and crusts has been explained with suggestions for the more rational treatment of the land, and, lastly, the occurrence and mode of formation of hardpan has been explained more clearly and more rationally than ever before. The work naturally leads up now to a study of the interesting and important subject of absorption by soils and the chemical and physical changes induced by fertilizers.

FIELD METHODS FOR A SOIL SURVEY.

After years of careful work the methods adapted to the field survey of soils have been perfected, so that now the field parties are quite independent of the laboratories, at least in the preparation of their

maps. A brief description of the field methods in use by the division at this time may be of value to those who are interested in the work.

In the field classification of soils all features are taken into consideration which appear in any way to influence the relation of soils to crops. The classification is based mainly upon the physical properties and condition of the soil as determined by the soil expert, but it is not based solely on this. Any chemical feature, such as deposits of marl, of highly calcareous soils, or of highly colored soils, is considered. as well as the character of the native vegetation and the condition of the crops. The topography of the country is often a very safe guide in outlining the boundaries of soil conditions. For this reason it is very advisable that there should be reliable maps of the different districts to base the soil work on and that these maps should show the important topographic features.

In order to make the maps of the greatest possible local value it has been decided to publish the soil maps, so far as possible, on a scale of 1 inch to the mile. Local variations in the character of the soil of less than one-fourth of a mile in extent are generally ignored. unless this variation constitutes a very prominent feature, such as a strip of meadow land along a stream, or unless there are a number of small areas by which a certain character is given to the district. For example, if rocky areas occur, small in each case, but extending over large areas, they should be indicated in some way upon the soil map.

The basis for the field classification of the soils of the Connecticut Valley may be seen from Mr. Dorsey's report. The meadow land is not only set off as a distinct physiographic feature, depending upon the topography of the country, but it is a very fine sediment of silt and very fine sand, which is easily recognized and is distinct from any of the other soils of the valley. The judgment of the soil expert in the field in a matter of this kind in deciding on the texture of these soils is very reliable.

The Podunk loam is a grade coarser than the meadows. and this also is very apparent to the observer in the field. The difference in texture in these soils can be recognized quite clearly in dried samples in the laboratory. The difference in the character of the vegetation and in the relation of crops as seen in the field is very marked.

Extending back from the river on either side and at higher elevations is the Hartford loam, which is still coarser in texture, while the Windsor sands are very coarse angular quartz grains with a little fine gravel. The Triassic stony loam has a peculiar Indian red color and contains fragments of stones grading up in size to boulders. The Enfield loam is apparently a deposit of the Hartford loam immediately upon the Triassic stony loam, with an average depth of about 18 inches. The Chicopee gravelly loam, covering a large area in the northern part of the district, has so much gravel as to form a very conspicuous feature. These features, upon which the classification of these Connecticut soils

is based, are quite plain and distinct enough in the field to outline the soil areas.

In the preliminary work in Florida, which was mentioned in Bulletin No. 13 of this division, it is evident that the classification of the soils there had to be made mainly from the distribution of the native vegetation. The different classes of soils there varied but little in their physical and chemical properties, but there is a very great difference in the native vegetation and in the adaptation to crops. The reason for this is not at present understood, but it is mentioned here to show that the basis for the classification of soils differs under different circumstances.

The survey of the alkali soils of the far West is much more difficult, as it involves other determinations and observations in the field. There should always be a soil map, an alkali map, an underground water map, and where sodium carbonate exists in appreciable quantities a separate map should be made showing the distribution of this pernicious substance. It is very important that the data for the soil map be first collected and the soil districts outlined on the best available base map. This will enable a much more intelligent study of the alkali problem to be made than if the distribution of the soils had not previously been determined. An example of this can be seen in the Salt Lake sheet which accompanies Mr. Gardner's report.

As a rule the clay soils on the flats and draws of the great alkali plain west of Salt Lake City contain the greater amount of alkali, the loam soils next, then the sandy loam, and finally the sandy soils. This is partly due to the texture of the soil and the influence of this texture on the drainage, and partly to the physiography of the country as determining the drainage question.

Having located these soils and considered the influence of the topography, a comprehensive study of the alkali conditions is much simpler.

In the preparation of the soil maps only such conditions as are apparent in the field, such as the texture as determined by the feel and appearance, the depth of soil and subsoil, the amount of gravel, the condition as to drainage, and the native vegetation or known relation to crops, are mapped.

Having determined upon the final classification of the soils of a locality, each well-defined area is established as a class and given a local name. No attempt will be made for the present to correlate a loam soil in the Connecticut Valley with a loam in the Susquehanna Valley in Pennsylvania unless the two are very clearly identical in origin, in character, in relation to crops, and under essentially the same climatic condition. If there is any apparent difference it is preferable to give each a local name and describe each separately in the most careful and exhaustive manner.

Having decided upon the classification, samples should be taken from each soil formation in order to study the texture and chemical

composition. For this purpose each area should be represented by at least eight or ten samples so selected that they will represent the average conditions of the area. The depth to which these samples should be taken depends somewhat upon the locality. In the eastern district the samples are usually taken to a depth of 3 feet and occasionally deeper. In the western district, where the soils are more uniform and where the alkali conditions are important, the samples are usually taken to a depth of 6 feet and occasionally deeper. The samples representing any particular formation should be fully described and such a number of them taken for examination, both physical and chemical, as may be thought necessary to bring out the striking features of the soil. The information so acquired will be used, not as heretofore to base the classification upon, but only to describe the samples mentioned in the text and to show the relation of the different soils of the area.

In the construction of the alkali maps it was formerly the practice in this division to take borings at more or less regular intervals along section lines and afterwards construct a map from the field notes after they had been corrected and the figures reduced in the laboratory. Much time can be saved, however, and greater accuracy secured by preparing the maps in the field as the work progresses, as is always done in the case of the soil maps.

Having outlined the soil areas, each area should be studied in sufficient detail to determine its condition as regards alkali. Very frequently, from the character of the soil and the topography of the land, the conditions of alkali over extensive areas can be very satisfactorily determined with a very few salt determinations. The alkali conditions of each soil should therefore be studied in this way.

It is usual to make borings for alkali work to a depth of 6 feet or more. It has been found, however, that the data so collected is really more than is necessary for the construction of an alkali map. It is now considered sufficient to examine the first, third, and fifth foot of the boring for alkali salts and neglect the second and fourth foot.

In plotting the results on the map it has been customary to locate the borings on the base map and faintly indicate the salt content of the first, third, and fifth foot. Having determined the limits which it is desired to show upon the map, lines are drawn around the figures in such a way as to separate the areas falling within or without the limiting values. It has been found better to use judgment in the placing of these lines, based upon the salt content of these three depths, rather than to accurately outline the conditions of the surface foot or of any given depth below the surface. Very frequently from some local cause, such as a slight elevation or a ridge formed in the cultivation of the soil, etc., the surface foot may contain a small amount of alkali, while the lower depths will show an excessive amount. These lower depths thus serve to check any error that may occur from a consideration of the surface conditions. Furthermore, even if the surface foot is shown

to be free from alkali over a considerable area which has never been irrigated and excessive quantities are shown in the other depths, it would be entirely misleading to show the soil free from alkali as a surface map would, as trouble would very soon be apparent after irrigation was started. It is not considered advisable to publish maps showing the alkali conditions at different depths, but far better in arranging the map to rely upon the judgment of the soil expert in outlining what may be considered as safe, dangerous, or worthless soils, so far as alkali salts are concerned.

This work has formerly been done in the office after the salt content corresponding with the actual resistances in the field had been reduced. The present practice, however, is to map these salt areas in the field in the same manner as the soils are mapped. A salt map is usually shown in colors, these colors indicating the soils having a very small and safe alkali content, those in which the alkali is too strong for crops, and intermediate grades, which may be considered dangerous and which would have to be handled with care and judgment. In the work so far this medium grade has a limiting value of one-half of the maximum—that is, if the maximum amount for a crop of any particular kind of alkali is 0.50 per cent, the lower limit of the danger line would be placed at 0.25. This is an arbitrary figure, but one which seems to be justified by the facts.

In testing the limiting value it is customary to look for a crop such as alfalfa or wheat, which is showing the effect of alkali in some portion of the field. Very frequently the middle of the field may begin to die out while the edges are still flourishing, or perhaps one corner will show the effects of alkali before the rest of the field is affected. By careful work on such a field as this the limiting value can be determined. The electrical resistance of the soil at various points in such a vicinity should be determined, corrected for temperature, and the limiting value be selected from the resistance figures so obtained.

As a result of the work this season, the following directions have been issued for the guidance of the field parties:

DIRECTIONS FOR MAPPING ALKALI SOILS IN THE FIELD.

The contour intervals for the alkali maps are to represent, respectively, 0.20, 0.40, 0.60, 1, and 3 per cent of salt in the dry soil. The maps are to be constructed in the field directly from the resistances. The work is to be standardized in each district in the following way:

Take eight or ten crusts, including the top inch of soil; or, if crusts can not be obtained, take the strongest alkali soils from different places over the whole area. Fill a large cup or tumbler about one-third full with a crust or soil, using more or less according to the richness of the material, and nearly fill the tumbler with distilled water. Stir vigorously and allow it to subside for a short time. Treat the eight or ten crusts or soils in the same way. Determine the electrical resistance of the solutions in the cell. Take an amount of the strongest solution equivalent to at least 200 cc. having a resistance of 5 ohms, and add to it a volume of each of the others proportional to the resistances determined. This mixture, containing approximately equal quantities of salt from the eight or ten localities selected, is

evaporated to dryness on a common range in a graniteware saucepan. Before the salts begin to crystallize out and when the clay and organic matter are well flocculated, filter and evaporate the clear filtrate, stirring at the last to prevent caking. Gently heat the residue to drive off the water of crystallization of the sodium sulphate and sodium carbonate. If the original solution can not be filtered clear at any time before the salts begin to crystallize out, a second evaporation may be necessary.

A 10 per cent solution should be made of this salt in distilled water. The electrical resistance of this 10 per cent solution in any cell, divided by 0.24, will equal the resistance of a saturated sand or sandy loam soil in the same cell when completely saturated and at a temperature of 60° F., when the soil contains 3 per cent of salt. This solution is then to be diluted and the resistance determined at various concentrations, corresponding to the limiting values of the soil map for four grades of soil. The table for temperature reduction have been published in Bulletin No. 8 of the Division of Soils.

The dilutions are as follows, the figures representing cubic centimeters of the 10 per cent solution to be diluted and made up to 100 cubic centimeters:

To obtain limiting values.

Salt in soil.	Volume of 10 per cent solution in 100 cc.			
	s. and ssc.	sc.	scc.	c. and hc.
Per cent.	*cc.*	*cc.*	*cc.*	*cc.*
3.00	100.0	79.5	71.4	66.6
1.00	33.3	26.5	23.8	22.2
.60	20.0	15.9	14.3	13.3
.40	12.0	10.6	9.5	8.9
.20	6.0	5.3	4.8	4.4
Resistances to be reduced to 60° F. and divided by .24		.275	.29	.30

The result will give the cell resistance at 60° F. corresponding to the limiting values, to be inserted in a suitable table.

To correct for any lime sulphate which does not redissolve, take the resistance of the solution before evaporating. Then evaporate in a separate dish a measured portion, such as 100 cc., heat the residue to char the organic matter, dissolve, make up to the same volume as before, and take the resistance. Any difference in resistance will be considered due to salts having gone out of solution, and all resistances used in the limiting values are to be decreased by the proportional increase in resistance so found before being entered in the table. Or the weight of salt for the 10 per cent solution may be increased in proportion to the differences in resistance.

DIRECTIONS FOR ESTIMATING SODIUM CARBONATE AND CHLORIDS IN SOILS.

Take a known volume (or weight) of saturated soil, wash into a 250 cc. flask, and fill to the mark with distilled water. Take 50 cc. of the solution (a slight turbidity will not matter) and titrate with N/10 acid potassium sulphate, using phenolphthalein as an indicator. Then add a few drops of potassium chromate as an indicator to the same solution and titrate with N/10 silver nitrate.

One cc. N/10 Na_2CO_3 = .005266 grams Na_2CO_3.
One cc. N/10 NaCl   = .005806 grams NaCl.

Construct the sodium carbonate map in the field from the volume of solution used. Limiting values will be 0.3, 0.2, 0.1, and 0.05 per cent of dry soil. The limiting values

for each dish are found in the following way: Multiply the volume of saturated soil, represented by the solution taken for titration, by the numbers in the following table:

Na$_2$CO$_3$ in soil.	s. and ssc.	sc.	scc.	c. and hc.
Per cent.				
.30	.832	.752	.720	.689
.20	.454	.502	.480	.459
.10	.277	.251	.240	.230
.05	.138	.125	.120	.115

The results so obtained are the cubic centimeters of N/10 solution of sodium carbonate corresponding to the limiting values, to be inserted in a suitable table.

If it is desired to reduce the volume of N/10 AgNO$_3$ to per cent of NaCl in dry soil, the following formula may be used:

$$\frac{V \times .005806}{V' K}$$

V = cc. N/10 AgNO$_3$ solution used; V' = volume saturated soil represented in amount of solution titrated; K = constant for type of soil, as follows:

s. and ssc. (sand and sandy loam) = 1.46; sc. (loam) = 1.32; scc. (clay loam) = 1.26; c. and hc. (clay and heavy clay) = 1.21.

If the resistances are close to the limits, a temperature reduction should be made in the field and a decision reached there as to which class the soil should be assigned. This greatly simplifies the work, lessens the calculations, and insures greater accuracy, because with the soil areas in view and with the general topography of the country the boundaries of these limiting values can be more accurately drawn than if the work were subsequently done in the laboratory from the field notes.

In like manner, the sodium carbonate map can be constructed in the field from the amount of standard solution of acid potassium sulphate required to neutralize the alkali in a given volume of saturated soil.

In the work so far undertaken Hilgard's value of 0.1 of 1 per cent of sodium carbonate has been taken as the limiting value for crops. The minimum value for the danger line is taken arbitrarily as 0.05 of 1 per cent. The amount of acid potassium sulphate required to neutralize a soil containing 0.1 of 1 per cent of sodium carbonate can easily be determined for any given volume of saturated soil and the survey can then proceed upon this basis in the classification of the black alkali conditions. No calculations are therefore required, except the ordinary standardization of the solutions and the determining of the volume of the measuring dish and the amount of dry soil which it contains. When these are once accurately determined, the work can proceed quite rapidly.

The construction of the water map is, of course, the simplest of all. Data are secured of the depths of all surface wells and wherever water is encountered in boring for samples. From the data thus secured the areas are traced upon the base map.

A SOIL SURVEY IN THE PECOS VALLEY, NEW MEXICO.

By THOS. H. MEANS AND FRANK D. GARDNER.

INTRODUCTION.

The southeastern part of the Territory of New Mexico comprises three distinct topographic features. The mountains of central New Mexico, including the Guadalupes, White, and Sacramento mountains, with the Santa Fe Range, mark the western boundary of the great series of plains extending westward from the mountains of Arkansas. On the eastern boundary of the Territory of New Mexico the Great Staked Plains are the most important feature. These plains form an elevated plateau with a uniform slope to the east. The western escarpment of the plateau forms the eastern limit of the Pecos Valley. The Staked Plains once, without doubt, extended to the foot of the mountains, with their western boundary somewhere near the present foothills which bound the east slope of the mountains, but the gradual uplifting of the western edge of the plain, together with excessive erosion along the base of the mountain, formed what is now known as the Pecos Valley. The present topography of the land is the result of the erosion and sedimentation of the stream in this valley—the Pecos River. At some period in its history, a time perhaps corresponding with the glacial period of the North, the Pecos carried much more water than at present, and during this time dams formed along the river either of hard ledges of rock or, by the filling up of narrow gorges with drifting material, caused the water to back up into shallow basins extending over great areas of country. In these basins or inland lakes the waters descending from the mountains deposited large quantities of sediment. The most pronounced basin of this type has been recognized and named the Tayah Basin. This basin lies on the lower Pecos, with its northern extremity near the Texas-New Mexico line, and extends for an undetermined distance to the southward.

Between the Delaware and the Black rivers, in a stretch of broken country, a second dam probably existed, and this obstruction backed the water up to some distance beyond Carlsbad. The sediments entering this basin were largely from calcareous rocks of the Guadalupe Mountain, and the soil formed from these sediments, weathering under the arid conditions of New Mexico, carries large quantities of carbonate of lime.

Between Carlsbad and Seven Rivers the Pecos flows through rough country along the foothills of the Guadalupe Mountains, and in this section of the river another obstruction once existed. The lake formed by this dam extended as far north as Roswell and an undetermined distance westward from the Pecos. In this basin were deposited the sediments which form the soils of the Roswell and Hagerman farming district.

There are many minor basins and features of the Pecos River which were not studied, since their bearing upon the subject in hand is only of secondary interest.

The rocks out of which the valley was cut vary in age from the carboniferous of the Guadalupes through the Permian Red beds of the upper Pecos, above Roswell, to the Jura-Trias and cretaceous sediments of the Staked Plains.

The carboniferous rocks are composed almost entirely of magnesian limestone, with beds of shaly limestone and thin sandstone. Such rocks form poor soils under the arid conditions existing, since they contain large quantities of lime without much potash or phosphoric acid.

The Red beds consist of red sands and shales, with heavy beds of massive gypsum. Gypsum crystals are common throughout the formation, and indicate formation from inclosed basins of sea water.

The Pecos River drains nearly the whole of the southeastern third of the Territory of New Mexico. Rising on the east side of the Santa Fe Range, the stream flows as a typical mountain stream through the rocks of the mountains; then entering the horizontal rocks of the mesa country the stream assumes a meandering course broken at intervals by gorges and canyons. The general character of the Pecos below Roswell is a series of basins filled with lake sediments and separated by rough country and hard rocks, through which the Pecos River is at present cutting.

The main tributaries of the Pecos all come from the western side, and they, too, are mountain streams, rising in the White, Sacramento, and Guadalupe mountains. The upper branches of these streams flow throughout the year, but as soon as the level mesa country is reached most of the streams sink into their beds. During times of high water the streams flow throughout their entire courses. The water which sinks along the upper stream courses follows under ground the general course of the rivers and appears along the basins near the Pecos in the form of springs. During its course through the ground the water dissolves small quantities of soluble matter and most of the springs contain the common alkali salts.

Above Roswell the main Pecos has few tributaries of any size. From Eden south small quantities of water flow in its channel throughout the year, though as far south as Roswell the flow sometimes is hardly more than 50 cubic feet per second.

At Roswell there are several permanent sources of supply which flow an estimated quantity of about 200 cubic feet per second. The Berendos, a series of large springs, rise from the edge of the large gypsum plains which extend for a distance up the Pecos Valley. The water from these springs has its origin in the crevices and underground channels of these gypsum plains, which form part of the Red Beds, and no doubt comes from the upper Pecos, the streams entering from the west across this gypsum plain. All of the waters coming from gypsum areas contain more soluble matter than do waters from the limestone strata of the underground river basins. This can be accounted for upon the assumption that the gypsum had its origin in inclosed basins of sea water, which always contains calcium sulphate in solution, concentrating through evaporation. Owing to the small solubility of the gypsum, this is the first salt crystallized out, and even though the water does not concentrate so far as to precipitate a large proportion of the sodium chlorid and the other more soluble salts, yet it includes small quantities of these salts.

There are three sources or springs from these gypsum plains, all of which unite into one stream flowing approximately 50 cubic feet per second.

The North and South Spring rivers rise from the underflow of the Hondo Basin, and the same basin furnishes the artesian water of Roswell. The springs rise in ponds from a number of small sources, and these small sources no doubt come from different depths, as their difference in temperature and chemical composition correspond very nearly with the temperature and composition of a number of wells of different depths around Roswell. The water is found in the lower layers of the cone of Hondo alluvium, which was formed as the flood waters overflowed into the basin of the Pecos. The water, coming as it does from the Hondo River, enters the Pecos at Roswell. In the upper parts of the river irrigation water in sufficient quantity to irrigate a few small farms is found, but after passing the Capitan Mountains east of Lincoln the river rapidly loses its water, and before Roswell is reached the river bed is dry during part of the year.

The artesian water at Roswell corresponds in composition nearly with the water of the Spring rivers. The temperature of the spring and artesian water is high—from 68° to 72° F. The water in the artesian wells rises to about the height of the springs, and since the level of the springs is below the level of the plain around Roswell, the use of artesian water for the irrigation of these plains is not possible.

Below Roswell is a series of draws emptying into the Pecos River. These draws are generally dry, but in their lower part below the Northern Canal small springs of ever-flowing water are found. Most of this water can be accounted for as coming from the Northern Canal by seepage.

The Felix River enters the Pecos a few miles north of Hagerman and, though dry during part of the year, it has a few permanent springs

near its mouth. The Peñasco and Cottonwood are also streams of this type.

At Seven Rivers an artesian basin, similar to the Roswell artesian basin, is found. At this place there is a settlement which uses the waters of the springs and the Seven Rivers for irrigation.

At Seven Rivers the valley of the Pecos closes in and the country is more broken until Carlsbad is reached. Here the Pecos runs close to the foothills of the Guadalupe Mountains. The principal streams draining the Guadalupe slopes from the east are Dark Canyon, Black River, and Delaware River. Both of the two latter run water throughout the year, though the flow becomes as low as 10 cubic feet per second during part of the season.

The Pecos enters the basin of the ancient lake Toyah about the New Mexico-Texas line, and flows through this basin to a distance of perhaps 50 miles beyond Barstow and Pecos City. Below this point the river is of no interest agriculturally.

THE CLIMATE OF THE PECOS VALLEY.

The climate of the Pecos Valley is arid—that is to say, the rainfall is insufficient to furnish enough water for the growth of crops over the entire valley. The drainage and surface water, however, is sufficient to irrigate a certain percentage of the land. The amount of land which can be irrigated stands in a direct relation to the rainfall and run off, provided the water is stored. The average monthly and yearly rainfall for the four years—1895 to 1898, inclusive—is shown in the accompanying table as compiled from the Weather Bureau records:

Rainfall at stations in Pecos Valley.

Month.	Mountain stations.				Valley stations.		
	East Las Vegas.	Galina Springs.	Fort Stanton.	Lower Peñasco.	Puerta de Luna.	Roswell.	Carlsbad.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
January	0.60	0.48	0.70	0.93	0.93	0.60	0.34
February	.77	.51	.80	.22	.08	.52	.29
March	.76	.48	1.10	.06	.40	.35	.22
April	.82	.61	.70	.72	.32	1.06	.31
May	2.95	2.54	1.00	.52	1.36	1.22	1.22
June	1.99	1.10	1.90	2.13	1.58	3.02	2.32
July	4.13	5.14	3.10	5.99	3.51	3.83	2.59
August	3.43	2.43	4.00	3.11	3.06	1.91	2.35
September	1.62	1.13	2.30	1.61	1.07	1.05	1.09
October	1.93	1.31	1.50	2.24	1.24	1.88	1.05
November	.37	.43	.80	.10	.45	.34	.21
December	.68	.79	1.10	.86	1.09	.52	.64
Year	20.05	16.95	19.00	18.49	15.12	16.30	12.64

The stations given represent both the mountain and valley country. East Las Vegas. Galina Springs, Fort Stanton, and Lower Peñasco, are all in the mountains or foothills. while Puerta de Luna. Roswell, and Carlsbad are in the valley proper. The record at Fort Stanton is an average of seventeen years. ended 1891. The other records are for four years only. The greater part of the rain falls during the summer

months, from May to October, inclusive, in the form of heavy showers—local and of short duration. Falling, as it does, in torrents upon a dry surface, large quantities of the water flow over the ground and great floods are common in the streams. The lost rivers entering the Pecos from the west all have large bowlders in their beds, indicating violent torrents at some time during the year. Streams like the Dark Canyon at Carlsbad and the Felix south of Roswell, which are dry during the greater part of the year, have been known to suddenly fill their channels to overflowing with turbulent water from the heavy rains over the foothills and mountains. Streams of this character are the most difficult to manage, and when their control is attempted the works must be of such a cheap nature as to allow replacement every few years, or so substantial and so well protected by waste ways that their destruction is impossible. The first dam constructed, 6 miles above Carlsbad, was considered well protected with waste gates, but a heavy flood from the upper Pecos filled the dam so rapidly that water overflowed its crest and cut its way through the dam in a few minutes. A disaster of similar nature in Lake Macmillan was only prevented by cutting the dike which runs west from the dam.

The temperature of southern New Mexico is uniformly high in the valley, with very low relative humidity. The evaporation from a water surface is great. It has been estimated at 10 feet annually, though no complete years' records have been kept. During the spring of 1899 the evaporation from Lake Macmillan was measured as high as $4\frac{1}{2}$ inches per week. This represents probably a maximum evaporation for that locality. The mild character of the winters, the moderate elevation of the valley, and the dryness of the atmosphere all tend to render the climate beneficial to persons suffering with pulmonary diseases.

HISTORY OF IRRIGATION IN THE PECOS VALLEY.

Twenty years ago farming in the Pecos Valley was confined to a few small farms under irrigation. Long subject to raids from hostile Indian tribes, agriculture was confined to stock raising. The first white men to enter the valley were cattlemen, who did all in their power to discourage general farming, and as late as 1889 irrigation was found only on a few small places where ditches had been taken out of the streams. At Roswell the permanent water of the Spring rivers and the ease with which it could be put on the land, encouraged the most extensive farming. Private ditches were run from the North and South Spring rivers, and the extension of these same ditches forms the irrigation system of Roswell today. In the lower valley irrigation was confined to two farms in the Pecos Valley.

In 1889, encouraged by the success of irrigation in Arizona and southern California, a large company was formed to develop the Pecos Valley, and the present systems of irrigation are in a great measure the result of the investments made by this company. The plans of the

company contemplated installing an enormous irrigation system, heading in the canyon above Carlsbad. The canal was mapped to extend as far south as the New Mexico-Texas line. In Texas a second system was to irrigate large tracts of land around Pecos City and Barstow. These plans contemplated the simple diversion of the Pecos, for, according to the statement of competent engineers, as published in the company's pamphlets, the flow of the Pecos is 1,000 cubic feet per second at its lowest stage. The Pecos, as a matter of fact, flows as low as 100 cubic feet, at low stage, a few miles above Carlsbad. The construction of the large storage reservoirs easily overcame this error on the part of the consulting engineer, but at the same time it introduced a difficulty in the use of the water which is very nearly insurmountable—that is, the concentration of the waters through evaporation.

Upon the establishment of the irrigation plant at Carlsbad settlers were brought in from Europe. Most of these people were ignorant of American agricultural practices, and particularly ignorant of agriculture under irrigation. The officers of the irrigation company attempted to follow blindly the practices of other irrigation districts. Attempts were made to introduce plants, trees, and shrubs from southern Europe. Large amounts of money were spent upon theoretical schemes, misleading statements were made about the wonderful productiveness of the soil, and the credulous immigrant invested all his wealth at the suggestion of the promoters. Misled, living in a land so different from their native country, many of the attempts of the settlers resulted in failure. There can be no question but that many of these early failures were due to ignorance on the part of the farmer, and also were due to the attempt to grow on a large scale plants entirely unsuited to the climate or soil. Extensive farming, that is to say farming on a large scale, has also been the cause of many failures. Irrigation farming to be successful must first be intensive, then extensive. Ignorance of the true conditions existing in soil and water and the attempt of the original promoters to conceal the true state of affairs from the settlers have also been the source of much failure. Since the farmers have begun to realize that grapes, fruits, grains, and truck crops were not the kind of crops which gave encouraging results at the start, a gradual change in the agricultural practices has taken place. Alfalfa and cattle or sheep raising are at present the industries of the valley, and with such change a much more healthy state of affairs has sprung up. In the Carlsbad district, and to a lesser extent throughout the valley, sugar beets form a money crop at the present time.

The Roswell area is the result of a gradual development by private resources, and the growth has been slower and more substantial. The company bought up the greater part of the land, with the water rights, in order to obtain control of the surplus water from the Spring rivers and the Berendos for use in the Northern Canal. The Northern Canal was constructed as a part of the general scheme for the valley, but it

has never been used as far as originally mapped. Under the canals now owned by the irrigation companies a water right is sold with the land, but a yearly water rent of $1.25 per acre is charged. The rental supposes the use of $2\frac{1}{2}$ acre-feet of water per acre. Under the private canals and the land recently sold by the Roswell Land and Water Company in the Roswell area, an interest in the ditch is deeded with the land, the irrigator yearly contributing his share toward the support of the ditch.

THE IRRIGATION SYSTEMS OF THE PECOS VALLEY.

Excluding the small private irrigation ditches, which are found along the head waters of all of the tributaries of the Pecos River, there are four great systems of irrigation in the valley.

The Roswell irrigation system derives its water from the North and South Spring rivers, and the North, Middle, and South Berendos. From each of these sources a number of small ditches are taken out which supply the farms of the district. These canals were originally constructed by private enterprise, but were later bought up by the irrigation companies and their surplus water turned into the Northern Canal for use at Hagerman.

The Northern Canal system receives the unused, waste, and drainage water from the Roswell district, together with water from the Hondo when that stream is flowing. The Northern Canal flows from 90 to 125 cubic feet of water per second. The canal starts at a dam in the Hondo directly east from Roswell. This diverting dam collects the various waters of the Berendos, North Spring River, and the Hondo River, and where the canal crosses South Spring River a second dam is constructed, which diverts the water of the South Spring River. For a distance of nearly 20 miles below South Spring River no water is taken out from the canal. On both sides of the Felix, level farming land is watered from the Northern Canal. The canal extends to a distance of about 5 miles beyond the Felix River.

The Southern Canal system derives its water from the Pecos River by storage. Two large reservoirs have been constructed—one at Seven Rivers, being 8 miles long and an average of $1\frac{3}{4}$ miles wide, while the second, a much smaller reservoir, is situated 6 miles above Carlsbad. From the lower reservoir the water is turned into a canal 70 feet wide at the top. Four miles below the dam the canal divides, the main branch crossing the Pecos by a terreplein and flume and the smaller branch following around the east side of the river. The eastern branch at present stops at a point opposite Carlsbad, though the canal was planned to run about 18 miles below Carlsbad and discharge into an alkali lake (Lake Surprise). The western branch or Southern Canal proper carries from 200 to 225 cubic feet of water per second. The canal is 35 feet wide at the top and has a fall of $1\frac{1}{2}$ feet in 5,000. Over a great part of its course only the lower side is banked, and the water extends back

into draws forming smaller lakes with a considerable storage capacity, though the loss by seepage and evaporation from these lakes is considerable and overbalances the advantage of storage. The water is taken out from the main canal through a system of head gates situated at convenient points. These main laterals are in turn divided into laterals and sublaterals. The entire control of the gates is in charge of the " ditch riders," who open and close the gates as the water is desired. The water right is sold with the land, though a yearly rental of $1.25 per acre is charged. This is the basis of $2\frac{1}{2}$ acre-feet of water. A record is kept of the amount of water used by each irrigator and a proportional charge is made for all water used in excess of this quantity.

Some trouble has been anticipated from the filling of reservoirs by silt. No records are at hand to determine the amount which has been deposited during the time the reservoirs have been used; but large quantities of mud have been and at every flood are being deposited. The water of the Pecos at flood carries from 5 to 10 per cent by volume of silt, the greater part of which is deposited while standing in the reservoirs. This engineering feature of the problem of water storage requires very careful consideration before more large storage reservoirs built on these mud-ladened flood streams.

At the town of Carlsbad a substantial masonry dam has been constructed, which furnishes sufficient power for the electric lights of the town, and also pumps water to a masonry reservoir upon the hill east of town.

About 13 miles below Carlsbad the Hagerman Canal takes water from a small diverting dam across the Pecos. This small canal was planned originally to supply water to a farm on the east bank of the Pecos River in the basin of the old Lake Surprise. The canal was afterwards extended nearly 10 miles, in one place widening out into a lake $1\frac{1}{2}$ miles long and one-half mile wide, with an average depth of 30 feet. This lake was formed by a short dam, the canal being taken out at one end of the dam. This canal and lake have been abandoned for several years and the canal is used only as far as the Hagerman farm, a distance of perhaps 2 miles from the dam. The canal runs through sand dunes nearly all of its course and great difficulty is experienced in keeping it clear of drifting sand.

The Barstow and Pecos City system was originally planned to cover great tracts of the level land of the Toyah Lake basin. All of the irrigation on the west side of the river has been abandoned and the present system waters the east side around Barstow. The water is diverted from the Pecos without storage, taken out on the west side, flumed across to the east side, and distributed.

THE ROSWELL DISTRICT.

The Geology of the Roswell Area.

The Roswell area, lying as it does upon the junction of the Pecos and Hondo rivers, consists of more or less perfect terraces cut by these streams in the basin sediments which once filled the valleys of the

streams. Rock is not exposed, except in a few areas on the bluffs bordering North Spring River on the north. Here the gypsum of the plains to the north is exposed and in all of the soils of the Roswell sheet gypsum is found in some quantity, in places forming a pure gypsum subsoil, but of such a local nature and in such small areas that these points were not mapped. Crossing the North Spring River and Hondo bottoms the land ascends to the second terrace, upon which is nearly the whole of the farming district of Roswell. Above this is the upland prairie or third terrace—land too high to receive water from the spring rivers. There has been more or less intermixture of the soils of these terraces, but their general characteristics are well preserved.

SOILS.

The soils of the Roswell area have been classified under four types:
1. Pecos sandy loam.
2. Roswell sandy loam.
3. Roswell loam.
4. Hondo meadows.

These types are indicated in colors on the accompanying map. The lightest shade represents the upland terraces of Pecos sandy loam, and the deeper shades represent the Roswell sandy loam and the Roswell loam. The Hondo meadows are represented by a different color.

THE PECOS SANDY LOAM.

The Pecos sandy loam is a light loamy soil covering great areas of the prairie land above the canal and extending up the Hondo River along its terraces. This soil represents the uppermost terrace of the basin deposits. The boundaries of the soil and of the basin were not determined, but the basin is known to extend over a territory more than 15 miles in width from the Pecos and extending from the Hondo south nearly to Seven Rivers. The native vegetation consists of blue and black gramas, woollyfoot, a little mesquite and needle grasses, together with occasional cacti and yuccas. The plains are entirely unwooded with the exception of a row of trees along each side of the Hondo.

This great tract of plain has been little cultivated on account of the scarcity of water. A storage system on the Hondo has been planned which if ever carried out will irrigate thousands of acres of this beautiful upland soil. The area of the Pecos sandy loam was examined in several places for alkali. Borings were made along the line of the old stage road from Roswell to Carlsbad and a few borings 6 or 7 miles farther west. Within the top 6 feet of the soil very little soluble matter was present, but in some places below this point small quantities of salts occur—in some cases as high as 0.25 per cent. The following table shows the results of the examination of this soil:

Soluble salt content of Pecos sandy loam.

Depth.	181.	182.	183.	186.	189.	190.	192.	193.
Feet.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.09	0.04	0.08	0.07	0.07	0.07	0.08	0.06
2	.05	.05	.05	.11	.09	.09	.07	.07
3	.04	.10	.05	.11	.09	.09	.11	.26
4	.06	.22	.04	.07	.13	.11	.08	.32
5	.26	.20	.04	.07	.16	.12	.11	.33
6	.27	.17	.03	.10	.15	.13	.15	.30
7					.15			.24
8					.16			.21
9					.17			.23
10					.22			.53
11					.21			

There need be no apprehension that this quantity of salt will ever damage the lands where adequate drainage is either natural or is artificially provided. However, seepage waters may collect and damage the land. When water is applied in quantity to a great tract of level land such as this, the seepage water is very apt to find difficulty in getting to the streams, and therefore collects until too near the surface of the ground for safety. This seepage water will also, without doubt, damage the lower lands and draws unless these are protected by underdrainage.

This area of Pecos sandy loam is underlaid only at a considerable depth by clay which will permit ready percolation of the seepage waters. This clay is exposed where the sandy loam has been removed, and is seen well developed in the Roswell loam. A typical section of the Pecos sandy loam, to a depth of 6 feet, would show a uniform loam throughout, so that this clay will not interfere with underdrainage should such be desired.

The texture of this soil is represented in the following table:

Mechanical analyses of soils of Pecos sandy loam.

Diameter.	Conventional names.	4115. Roswell, 6 miles S.E. (0–12 inches).	4123. Roswell, 10 miles S.W. (0–24 inches).	4125. Greenfield, 10 miles W. (0–24 inches).	4126. Roswell, 10 miles S. (0–24 inches).	4128. Roswell, 12 miles S. (0–24 inches).
Millimeters.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
2 to 1	Gravel					
1 to 0.5	Coarse sand	1.11	Trace.	Trace.	Trace.	Trace.
0.5 to .25	Medium sand	2.55	3.95	1.52	1.22	2.05
.25 to .1	Fine sand	14.12	16.45	9.15	6.97	9.76
.1 to .05	Very fine sand	38.57	29	34.10	29.61	33.11
.05 to .01	Silt	13.17	15.18	17.34	19.30	19.02
.01 to .005	Fine silt	9.63	9.76	9.70	12.10	10.35
.005 to .0001	Clay	13.62	17	18.45	21.90	13.77
Salts a		1.60	3	1.85	1.46	1.46
Loss at 110° C		2.70	3.30	5.28	4.98	4.59
Loss on ignition		2.75	3.30	3.85	3.94	4.55

a Dissolved in 1½ liters of water used in mechanical analyses, mainly gypsum.

The mechanical analysis of this soil, when first made by the customary method in this division, showed as much as 30 per cent clay. This differed so much from the field observations, for in the field these soils were classed throughout as sandy loams, that the source of the differ-

ence was investigated. A microscopical examination of the soils showed them to be composed of small conglomerations of clayey matter cemented by carbonate of lime. By agitation with large quantities of water this carbonate of lime was partially dissolved, the clay loosened, and the resulting analysis would make the soil appear heavier than the field judgment would warrant; also it was found that there was a quantity of matter in the soil which dissolved in the water used in the analysis. This was not in all cases alkali, but was more likely to be gypsum and carbonate of lime, both of which are slightly soluble in pure water. This soluble matter is always included in the clay by the method employed in the analysis, and thus served to make the soil appear heavier than it really was. This soluble matter was determined in all cases and subtracted from the clay. The amount of soluble matter is given, but must not be confused with the alkali determination given in other tables.

The action of water upon this soil in the field produces nearly the same results as were observed in the laboratory, and where irrigated a difference can be seen in the apparent clay content of the soil. After irrigation continued for some time the sandy loam changes in appearance and character to a loam or even to a clay loam.

THE ROSWELL SANDY LOAM.

This soil differs from the Pecos sandy loam in being a little heavier, though the top foot of soil may be nearly of the same texture. It is underlaid at from 1 to 2 feet by a loam, and this in turn is underlaid at 5 feet by a clay loam or clay.

The native vegetation of this soil was originally the same as on the Pecos sandy loam, but since irrigation water has been applied all waste tracts are now covered with salt grass and alkali weeds.

The texture of this soil in the field was considered different from the soils of the prairies. The difference was so slight that the results of the mechanical analysis fail to show it, as appears from the following table; still the mechanical analysis is not considered perfectly reliable in these soils for the reasons stated above.

Mechanical analyses of soils of Roswell sandy loam.

Diameter.	Conventional names.	4099. Roswell, 3 miles SE.	4108. Roswell, 5 miles E.	4112. Roswell, 5 miles SE.
Millimeters.		*Per cent.*	*Per cent.*	*Per cent.*
2 to 1	Gravel...................			
1 to 0.5	Coarse sand	0.35	....	Trace.
0.5 to .25	Medium sand..............	1.90	.40	2.20
.25 to .1	Fine sand	15.87	12.40	17.80
.1 to .05	Very fine sand............	30	32.80	34.22
.05 to .01	Silt	14.83	15.65	14.46
.01 to .005	Fine silt..................	8.90	10.22	8.03
.005 to .0001	Clay	15.66	15	17.10
Salts dissolved in 1½ liters of water used in mechanical analysis, mainly gypsum.....		1.74	4.50	1.60
Loss at 110° C.............................		3.13	3.40	2.61
Loss on ignition...........................		7.15	6.25	3.60

There is little question but that the arrangement of the soil grains plays a great part in the field judgment of the texture. The application of the irrigation water separates the floccules and to a small extent gives the soil a much heavier appearance than the mechanical analysis shows. This fact is plainly to be seen in the Pecos Valley soils

The Roswell sandy loam may be considered the same as the Pecos sandy loam, with the upper part of the stratum removed, bringing the loam and clay nearer the surface. Since the alkali is more abundant in the lower layers of the Pecos sandy loam, it is evident that the salt should be more abundant in the Roswell sandy loam, which represents the lower strata of the Pecos sandy loam. Such was, no doubt, the case, though it has been found difficult to secure a sample of this soil which has not been irrigated. The following table represents the soil as near its original condition as it is possible to find:

Salt content of Roswell sandy loam before irrigation

Depth.	67.	Depth.	67.
Feet.	*Per cent.*	*Feet.*	*Per cent.*
1	0.07	5	0.36
2	.27	6	.25
3	.44	7	.20
4	.54	8	.20

After irrigation water has been applied to this soil a very different state of affairs is found to exist. The greater part of the soluble matter is dissolved in the irrigation water, and should this water be able to sink into the lower subsoil and flow off into the country drainage, most of this salt would be entirely removed from the soil and do no further damage. This soil, however, becomes heavier and more compact in its lower strata, and consequently the percolating water finds difficulty in penetrating to the stream channels. Thus accumulations of water follow and evaporation from the surface of the soil concentrates the soil moisture near the immediate surface of the ground. The salt either crystallizes out onto the surface of the ground or diffuses down into the soil slowly. If this state of affairs is allowed to go on unchecked the surface of the soil becomes too saline for agricultural plants to grow and the soil is abandoned to salt grass and other alkali vegetation.

The accompanying table shows the conditions found to exist in such soils after unchecked evaporation from a wet soil.

Soluble salt content of Roswell sandy loam after irrigation.

Depth.	135.	142.	27.	54.	144.	47.
Feet.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.09	0.06	0.45	0.66	0.16	0.41
2	.15	.06	.18	.44	.13	.52
3	.28	.10	a .30	.52	.12	.48
4	.26	.14	.15	a .47	.10	.42
5	.32	.18	.17	.33	a .10	.39
6	.34	.18	.17	.33	....	a .35
7	....	....	....	....	....	.36

a Water encountered.

Samples 135, 142, 144 illustrate soils in which water is not standing near the surface. Here the original salt has been washed down and away through the subsoil. In the other samples water has accumulated in the subsoil, and at the time examined stood at the depths noted. Through fluctuation in the level of this water table, the standing water at other seasons approaches much nearer the surface.

A general relation is to be seen between the depth to standing water and the amount of alkali within the surface foot of soil. The amount of alkali within the surface foot is the controlling factor in the cultivation of these soils; and, since agricultural plants refuse to grow with $\frac{1}{2}$ of 1 per cent alkali, the evaporation from the surface has already damaged some of the soils referred to in the table.

ROSWELL LOAM.

This soil differs from the Roswell sandy loam in having the clay near the surface. A typical section shows about 4 feet of loam underlaid by heavy loam and clay.

The Roswell loam is represented on the soil map by an area in the center of the Roswell sandy loam. This area is underlaid by impervious clay throughout, and, wherever it has been watered without proper drainage, water can usually be found at a depth of from 3 to 5 feet. The conditions of this soil with reference to alkali are nearly the same as in the Roswell sandy loam, but wherever evaporation has been allowed to progress unchecked the surface soil is at present charged with alkali. In some places this has gone on to such an extent that the soil should be classed as an alkali flat.

Soluble salt content of Roswell loam.

Depth.	33.	34.	39.*a*	41.	48.	49.
Feet.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.19	*b*1.34	1.69	2.76	0.42	0.72
2	.15	.45	.60	.93	.28	.36
3	*c*.22	.31	.43	1.14	*c*.22	*c*.31
4	.35	.31	.32	1.04	.20	.31
5	.36	.33	(*c*)	1.25	.16	.34
6	.36	.29	....	*c*1.04	.14	.32
8	....	....	....	.72	....	....
10	....	....	....	.44	....	....
12	....	....	....	.32	....	....

a Never irrigated.   *b* Water at surface.   *c* Water encountered.

Sample No. 33 represents the soil in nearly its best condition as regards alkali, but with standing water too near the surface. The texture of the Roswell loam in the field was classed as heavier than the Roswell sandy loam, though mechanical analyses of a few samples show very little difference. This again illustrates the difficulty of interpreting the texture of a soil from a mechanical analysis alone. The change in arrangement of the soil particles by the action of irrigating waters and the presence of the clay nearer the surface give the impres-

PLATE II.
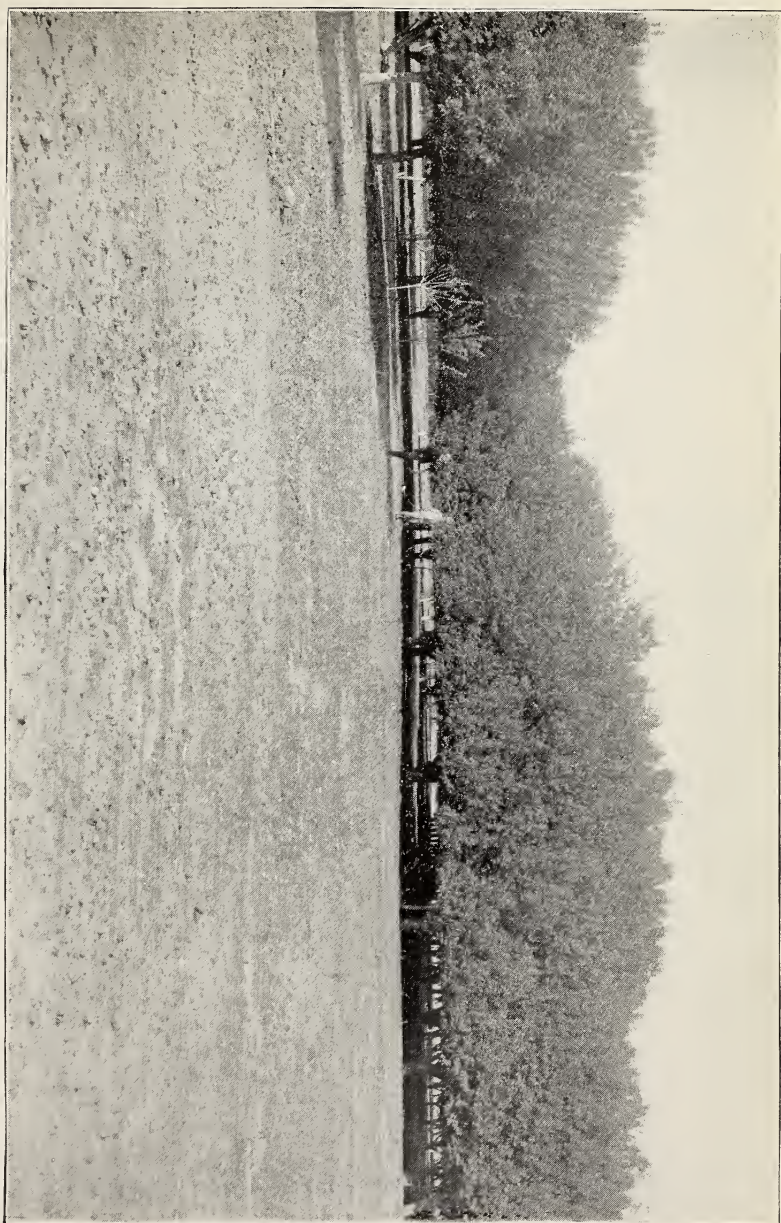
OLD APPLE ORCHARD, 5 MILES SOUTHEAST OF ROSWELL, N. MEX.

Where good natural drainage is found fruit trees do wonderfully well.

sion in the field that the Roswell loam is a heavier soil than the Roswell sandy loam or Pecos sandy loam, and it has been so classed. This shows that the holding power and its penetrability to water are often important factors in determining the character of a soil as well as the size of the grains.

THE HONDO MEADOWS.

Under the title of Hondo Meadows are included the low-lying lands along all of the streams, but, with the exception of a narrow strip along part of the South Spring River and a small part immediately along the Pecos, these meadow lands on the soil map are all along the Hondo River and around its junction with the Pecos. The term *meadow* is used in the same sense as in humid regions, and means low land, naturally wet from the proximity of the stream, though in the arid climate of the Pecos Valley the low-lying lands need not necessarily be wet before irrigation.

The soil of these meadows is formed from recent alluvium, and in its physical properties represents this mud, being heavy and silty. A typical section of the Hondo meadow land shows 3 feet of clay loam underlaid by clay.

The water of the Hondo is very muddy, and when fields are flooded with this water a thin deposit is left. The fertilizing value of the silt in suspension is considerable; in fact an analysis shows it to contain more plant food than the mud of the Nile River in Egypt.

Chemical composition of Hondo and Nile sediment.

	Hondo mud (Skeats).	Nile mud (Mackenzie).
Insoluble matter and silica	43.6	58.17
Iron oxide and alumina	21.4	24.75
Oxide of manganese		.09
Magnesia	2.1	2.42
Lime	5.7	3.31
Potash	1.19	.68
Soda		.62
Sulphuric acid	1.96	.20
Phosphoric acid	.3	.21
Carbonic acid		1.55
Organic matter	9.8	8.00
Nitrogen in organic matter	.32	.12

The application of water containing this mud can not but be of benefit to most lands in the valley. Its wealth of plant food is above that of the ordinary soils, and the nitrogen it contains should be of special value. The sediment often amounts to as much as 10 per cent by volume of the water, it is stated.

This analysis may be taken to represent the composition of the Hondo meadow soil. This soil is the richest in plant food of all the soils mapped. The sediment of the river represents the richest portion of the soils of the upper valley.

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From the position of these lands, subject to weathering from below by seepage waters from the higher lands, the evaporation from the surface of the soil has accumulated quantities of salt within the soil and at present nearly the whole of this rich land is given over to salt grass. Cultivation has been attempted at several points and the effect of underdrainage on the soils is readily noticeable. On section 33, one-half mile east of Roswell, a truck patch has been laid out on the Hondo bottom. Near the bluffs sloping from the second terrace to the bottoms the land is wet and alkaline and the growth of tender truck crops uncertain or impossible. Toward the bank of the Hondo, which at this point is cut down 8 feet below the level of the meadows, the soil is better drained and truck crops do well. Should drains be cut from the river back to the bluffs at intervals, the water seeping out from the uplands would be drained away and the salt already in the bottoms could be washed into the Hondo and so carried away. On section 34 an alfalfa field is growing on the Hondo flats. Along the foot of the bluffs, 150 yards from the river, the soil is wet and boggy, with salt grass the only vegetation. Close by the stream banks, however, the growth of alfalfa is heavy and luxuriant and grades down until, less than 100 yards from the escarpment of the terrace, it fails entirely to grow.

Perhaps the best illustration of the effect of drainage is seen upon the farm of Mr. Charles Bremond, on section 31. Here the Hondo makes a bend, and close to the river all around the bend the soil is in far better condition than farther back. The mechanical analysis of the Hondo bottom land shows it to be a much heavier soil than any other exposed in the valley. The sediment as originally deposited contains very little more clay than the Roswell loams, but from its position, being wet nearly all of the time, the soil particles break down and a much heavier soil is formed. The two analyses in the table represent the two conditions of the soil—the first column representing the sediment immediately after its deposition and the other soil formed from the weathering of this sediment.

Mechanical analyses of soils of the Hondo meadows.

Diameter.	Conventional names.	4145. Roswell, 3 miles E.	4119. Roswell, 1 mile E.
Millimeters.		Per cent.	Per cent.
2 to 1	Gravel...............		
1 to 0.5	Coarse sand...............	Trace.	....
0.5 to .25	Medium sand.............	1.46	0.76
.25 to .1	Fine sand..................	5.58	4.85
.1 to .05	Very fine sand.............	21.04	10.65
.05 to .01	Silt	35.69	12.35
.01 to .005	Fine silt..............	7.13	17
.005 to .0001	Clay	14.52	34.65
Salt dissolved in mechanical analysis.		.95	5.40
Loss at 110° C......................		5.57	7.47
Loss on ignition......................		7.89	8.63

U.S. DEPT. OF AGRI MEXICO
DIVISION OF S
MILTON WHITNEY ELL SHEET
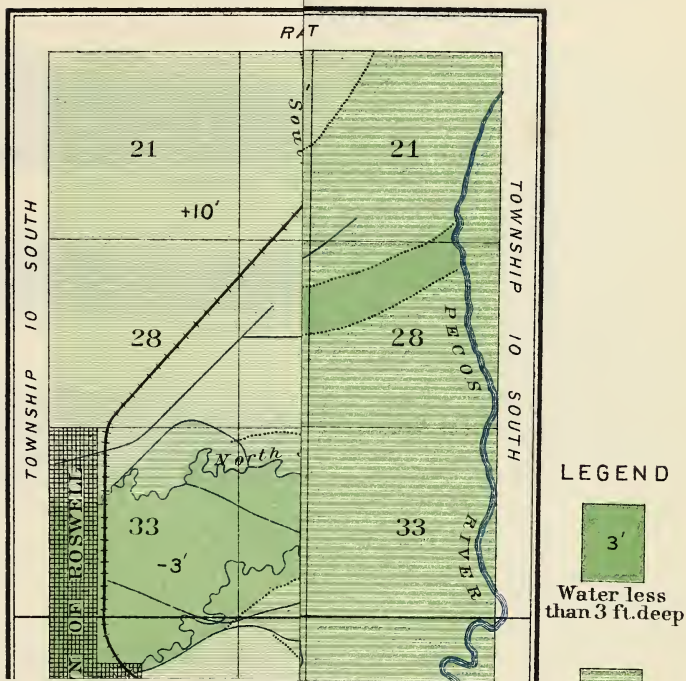
LEGEND

3′

Water less
than 3 ft. deep

UNDERGROUND WATER MAP

NEW MEXICO
ROSWELL SHEET

RANGE 24 EAST

RANGE 25 EAST

TOWNSHIP 10 SOUTH

TOWNSHIP 10 SOUTH

| 21 | 22 | 23 | 24 | 19 | 20 | 21 |

+10'

10'

+10'

South Berendo R.

Berendo R.

| 28 | 27 | 26 | 25 | 30 | 29 | 28 |

3'

3'

PECOS RIVER

North Spring R.

Hondo

River

Hondo

-3'

3'-10'

TOWN OF ROSWELL

| 33 | 34 | 35 | 36 | 31 | 32 | 33 |

-3'

3'

River

NORTHERN CANAL

| 4 | 3 | 2 | 1 | 6 | 5 | 4 |

3'

-3'

3'-10'

3'

-3'

TOWNSHIP 11 SOUTH

TOWNSHIP 11 SOUTH

PECOS VALLEY

| 9 | 10 | 11 | 12 | 7 | 8 | 9 |

-3'

Spring River

+10'

| 16 | 15 | 14 | 13 | 18 | 17 | 16 |

South

River

R. R.

3'-10'

South Springs

3'

R. R.

| 21 | 22 | 23 | 24 | 19 | 20 | 21 |

3'

3'

RANGE 24 EAST

RANGE 25 EAST

LEGEND

| 3' |

Water less than 3 ft. deep

| 3'-10' |

Water 3 ft. to 10 ft. deep

| 10' |
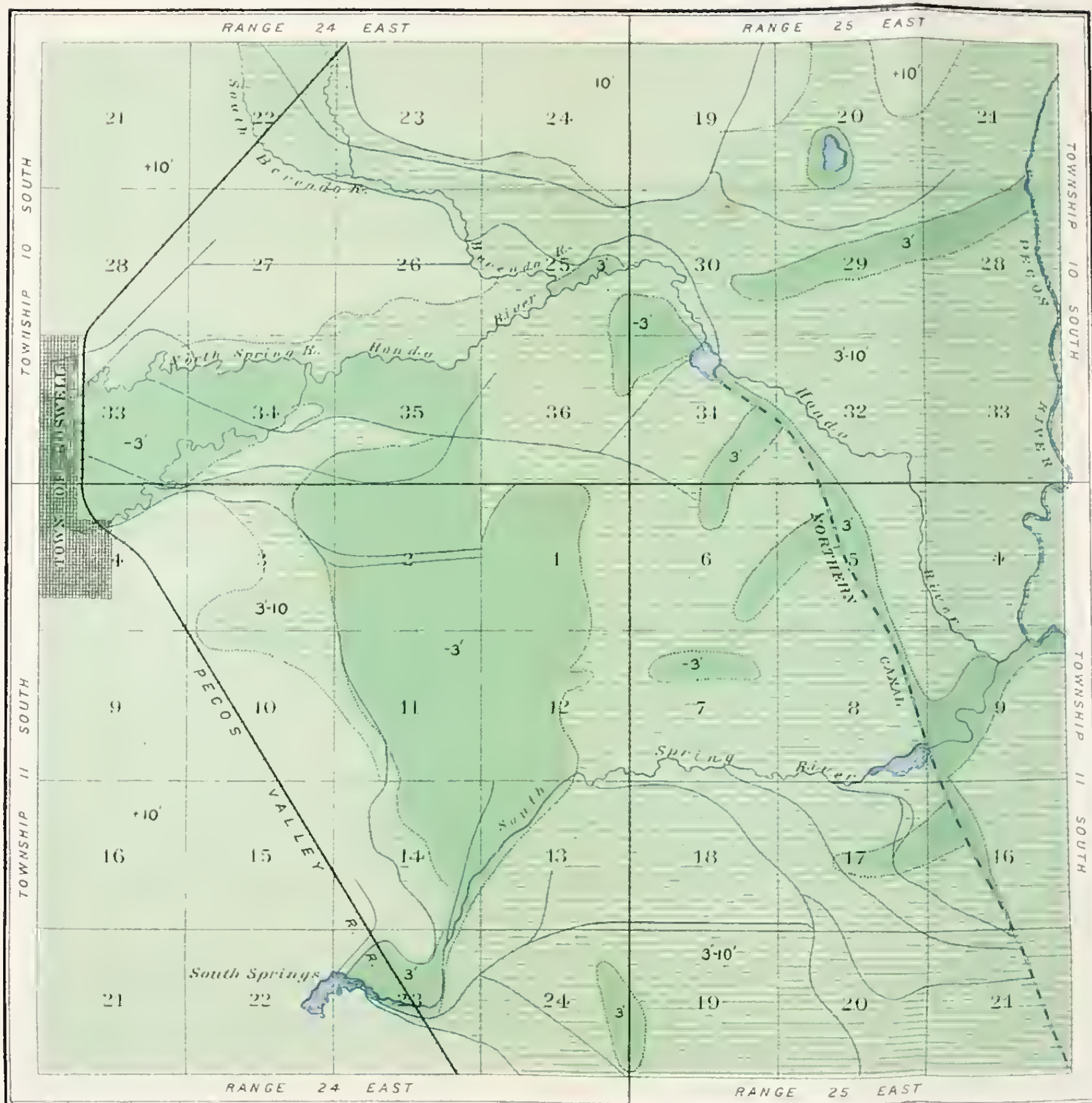
Water over 10 ft. deep

Figure 1 gives sections through Roswell, Carlsbad, Otis, and Florence and shows the relation of the soil at the different parts of the valley.
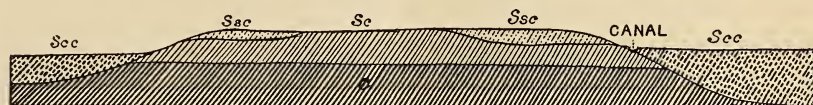
FIG. 1.—Sections in Pecos Valley, New Mexico.

(S = sand; Ssc = sandy loam; Sc = loam; Scc = clay loam; C = clay; $Congl$ = conglomerate; Gyp = gypsum.)

WATER SUPPLY.

The water supply from the North and South Spring rivers is good; that is to say, it does not contain enough salt to be harmful to vegetation in any way. The average water contains 75 parts of soluble matter to every 100,000 parts of water. About 49 parts consist of calcium carbonate (limestone) and calcium sulphate (gypsum), which are harmless to plants and crystallize out upon evaporation of the water. The remaining 26 parts consist of salts readily soluble in water and such as are likely to remain in solution and accumulate to such a degree as to be harmful.

The following analysis by Prof. E. M. Skeats, of Carlsbad, represents the average chemical composition of the salt dissolved in the water:

Chemical composition of the North and South Spring rivers, in parts, per 100,000 parts of water.

NaCl	8
CaCO$_3$	18
CaSO$_4$	20
MgSO$_4$	16
K$_2$SO$_4$	2
Silica, alumina, and iron	1
Water of crystallization, etc.	10
Total solids	75

Since most of our agricultural plants are able to grow with their roots in solutions containing as much as 1 per cent of these readily soluble salts, it would require evaporation and concentration of the Spring River water to one-fifteenth of its bulk in order to kill vegetation. Such a concentration can easily be avoided within the soil. By the application of 1 acre-foot of this water about 700 pounds of harmful salts are added, and, since 15,000 pounds per acre-foot can be taken as the maximum amount of salt allowable for plant growth, it would require nine years' accumulation of irrigation waters, allowing $2\frac{1}{2}$ acre-feet of water for each year, and supposing none of the salt washed out of the land. Such a condition could hardly exist, for a certain percentage of the salts is washed down below the first foot. Moreover, part of the salt is annually removed in the crop. Four-tenths of 1 per cent of soluble salt in a soil capable of holding, when saturated, 40 per cent by weight of water gives a concentration of 1 per cent in the soil moisture when the soil is saturated.

UNDERGROUND WATER.

One of the maps accompanying this report shows the depth to standing water during June, 1899. The depth is shown by three shades of green, the lightest shade showing land in which water can not be found by boring 10 feet. The intermediate shade shows land in which water is to be found between 3 and 10 feet in depth. Such land as this, if the water approaches the higher limit, is in danger of becoming too wet and the level of the water table should be carefully watched; and, if it rapidly approaches 3 feet, drainage must be furnished to prevent the water from rising above 3 feet. The reason for giving this land a special tint is that it is approaching the limit, and may need drainage. The darkest tint shows land which is at present in need of drainage, for at the time it was examined water was found within 3 feet of the surface. For such land there can be no question but that its great need is underdrainage. Few plants, none of which are used as agricultural plants in the Pecos Valley, are able to grow to advantage with their roots immersed in water for more than a day or two at a time, and, as most of our common plants send roots as deep as 3 feet, the level of standing water should be kept below this level. Particularly is this true of arid regions, where there is not so much difference between soil and subsoil as in the East. Alfalfa, which is the most important crop of the Roswell area, sends its roots to great depths. Cases have been noted where the alfalfa grew luxuriantly for two or three years, but suddenly began to sicken and die. Investigation proved that the plants grew all right until the roots reached the water table. Here, in their effort to reach farther into the subsoil, the roots were partly immersed in standing water and the crop suffered.

The scale upon which this map is printed does not permit detailed representations of each section of land. There are no doubt small spots

within the area shown as in need of immediate drainage which are at present in fair condition for crop production. The map is intended to show in a general way the conditions found existing during June, 1899, and must not be interpreted as representing the conditions at any other time. The entire condition of the land may change with the seasons, and during some other season of the year the water level may be very different. On the map all of the lands below the irrigating canals have standing water at less than ten feet. Such is generally true, though there are a few isolated points immediately along the bank of the Hondo, or under some land never irrigated where water stands at a greater depth than ten feet. Throughout the greater part of the Roswell loam, where clay is found near the surface of the soil and in the draws and close to the river channels, the land is wet and water stands at less than three feet.

The Alkali of the Soils.

One of the maps accompanying this report shows the conditions of the ground with reference to alkali. The three colors indicate the amount of alkali in the soil; soil containing from 0 to 0.25 per cent of alkali; soil containing 0.25 to 0.50 per cent, and soil containing over 0.50 per cent. Or the map shows (1) the areas of land which are free from harmful quantities of alkali; (2) the lands which contain harmful quantities of alkali, but not enough alkali to prevent the growing of crops; and (3) the lands which contain too much alkali for cropping.

The term alkali, as used throughout the West, designates any soluble matter in a soil or water. The term does not mean that the salts are alkaline or basic in a chemical sense, for the greater part of these salts are neutral, and in some cases even acid salts have received this name. There are two kinds of "alkali" commonly recognized, (a) white alkali and (b) black alkali.

The white alkali is composed of one or more of the following salts, named in the order of their importance: Sodium chlorid, sodium sulphate, magnesium sulphate, calcium chlorid, magnesium chlorid with, in some districts, borates and nitrates. The essential constituent of black alkali is sodium carbonate, though this salt is never pure, but is mixed with sodium bicarbonate and the salts which form the white alkali. These salts are formed through the weathering of the rocks, and in districts of light rainfall the amount of seepage through the soil is insufficient to wash them away. There is therefore an accumulation in most arid soils—the amount, other things being equal, varying inversely as the rainfall of the district.

In some places the alkali is the accumulated salt from the evaporation of inland lakes. All river water contains soluble matter, and when this water enters an inclosed basin where the waters evaporate an accumulation of salts is the result. The muds, silts, and sand left by this lake all contain soluble matter, and upon applying water by irrigation to such soils the alkali, which may not be apparent on the surface

of the soil, is brought to the surface by the water, as it rises through capillary attraction. These inclosed basins sometimes represent the most difficult conditions with which the farmer has to deal, for the salt commences to accumulate in the lowest portions of the basin and extends up the sides of the basin as the amount of salt brought in increases. The great expense or even impossibility of draining such basins is the great barrier in the way of their reclamation. The Great Salt Lake of Utah is the remnant of a great lake, and its waters to-day represent the mother liquor from the concentration of great quantities of water.

In past geological ages arms of the ocean were sometimes cut off from the main ocean and the waters concentrated by evaporation until part or all of the burden of soluble matter was deposited. Beds formed in this way to-day, when elevated above the level of the sea and exposed to erosion, give rise to quantities of alkali. The Red Beds, forming the great plains north of Roswell in the Pecos Valley, and underlying the Staked Plains to the east, were deposited in this way, and though no beds of salt are found, yet all of the soils from this formation contain soluble matter. Beds of gypsum were deposited, thus indicating that the ocean water was concentrated by evaporation. Included within this gypsum are small quantities of soluble salt. If beds of these salts were ever deposited, the greater part has been removed by solution, for to-day no deposits of salt within this formation in New Mexico have been found, so far as known.[1]

Another source of alkali in the Pecos Valley is from the decomposition of volcanic rocks. To the west of the Pecos great areas of apparently recent lava are found, and associated with the lava are alkali springs of varying degrees of concentration. Some of the deposits of gypsum in the Pecos Valley can be accounted for only on the assumption that the gypsum is the result of the action of acid waters upon the limestone. Even though the lava flows were not associated with alkali springs, the decomposition of the igneous rocks would give rise to the formation of alkali salts, and without doubt the igneous rocks west of Roswell are the source of parts of the alkali salts.

The alkali of the Roswell area is entirely the white alkali, as far as observed. Many spots were pointed out as being due to the black alkali, but they were undoubtedly due to calcium chlorid. Sodium carbonate can hardly exist under the prevailing conditions.

It has been pointed out by Hilgard that gypsum is an antidote for black alkali under certain favorable conditions. If the soil be well drained and aerated, the black alkali, sodium carbonate, in contact with the gypsum is more or less completely converted into the less noxious white alkali, sodium sulphate. The reaction may be expressed thus:

$$Na_2CO_3 + CaSO_4 = Na_2SO_4 + CaCO_3$$
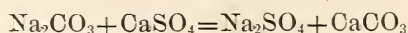
[1] Since this was written it is reported that a bed of rock salt over 400 feet deep has been encountered in boring for an artesian well at Carlsbad.

On the other hand, if the soil be not well drained, that is to say, conditions exist favorable to the retention of carbon dioxid and moisture, a reverse reaction will predominate, which may be indicated thus:

$$Na_2SO_4 + CaCO_3 + CO_2 + H_2O = Na_2SO_4 + H_2Ca(CO_3)_2 = 2\ H\ NaCO_3 + CaSO_4$$
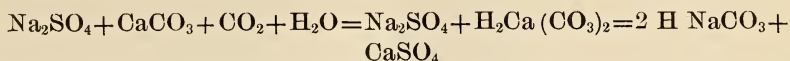
and the sodium bicarbonate ($H\ NaCO_3$) being a very instable compound, always inverts to some extent with the formation of sodium carbonate ($Na_2\ CO_3$), the undesirable constituent of black alkali.

Somewhat similar reactions take place when gypsum comes in contact with chlorids in solution or in a wet soil. Calcium chlorid and sodium sulphate will be formed, which is indicated thus:

$$2\ NaCl + CaSO_4 = Na_2SO_4 + CaCl_2$$
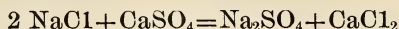
There will now be present in the solution, sodium chlorid, calcium sulphate, sodium sulphate, calcium chlorid, as well as the ions formed by the dissociation of these salts. If the soil be well drained and sufficient water drains through it, the soluble salts thus formed are rapidly leached away; but if the soil be not well drained, that is to say, if it contains standing water near the surface, there will be a gradual evaporation of the water with a concentration of its salt contents. At first sight it would appear that the calcium sulphate, being so much less soluble than the other salts, would be precipitated as a solid before any of the other salts; more and more being formed from the sodium sulphate and calcium chlorid and precipitating in turn. But this process will take place, if at all, to a much less extent than is generally supposed. It is to be remembered that the solution is becoming more and more saturated with respect to the sodium chlorid. It follows, from the investigations of Treadwell and Reuter, and from experiments in this laboratory, which will be described later by Dr. Cameron, that the amount of gypsum dissolved—its constituents being held in solution as calcium chlorid and sodium sulphate—is very greatly increased with the concentration of the sodium chlorid.

It thus comes about that as evaporation proceeds the solution is actually becoming richer and richer in the very soluble calcium chlorid, and finally it separates as such along with or after the other readily soluble salts. On resolution, being much the most soluble of the salts in the mixture, it would be the first to dissolve, and from the fact that it has a common ion with sodium chlorid, would retard the solution of that otherwise very readily soluble salt. It would increase the solubility of the less readily soluble sodium sulphate if it remained in contact with it sufficiently long for equilibrium to take place. But if it is quickly brought to the surface by capillary forces, or by diffusion, and then quickly concentrated by rapid evaporation, there would be a concentration of the calcium chlorid in the upper portions of the crust.

In several spots in the Pecos Valley considerable quantities of calcium and magnesium chlorid were found in the *crust* on the soil. It is probable, as will be seen from the above reasoning, that but small quantities would be found at any depth in the soil itself. These crusts containing calcium chlorid have a dark appearance quite similar to the true black alkali. Indeed, they are locally known as black alkali, though their characteristic feature is the presence of much calcium or magnesium chlorid, not that of sodium carbonate. The reasons for this blackened appearance are not obvious, and the evidence at hand is too meager to warrant any suggestion at present. It is worthy of note that these spots are of necessity damp or wet—a condition favorable to the formation and retention of carbonic acid. But it will require further investigation to say definitely whether this be a factor in the production of the observed results.

Analyses of alkali crusts from the Roswell area.

No.	Locality.	Calcium sulphate.	Magnesium sulphate.	Sodium sulphate.	Sodium chlorid.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
4092	Sec. 35, T. 10 S., R. 28 E......................	14. 17	28. 05	47. 99	9. 82
4093	Sec. 35, foot of gravel hill....................	9. 09	38. 42	41. 15	11. 33
4097	Bremond crust................................	13. 58	15. 73	35. 77	34. 90
4107	Black crust, Bremond.........................	6. 85	12. 86	50. 90	29. 41
4139	High spot, Michelet...........................	45. 57	17. 53	1. 44	35. 46
4149	Tule crust, E. of Northern canal..............	4. 03	21. 64	64. 77	9. 57

Of the salts shown in these analyses sodium chlorid is the most harmful to plants. It is generally stated that most agricultural plants can grow with 0.25 per cent within the surface foot of the soil, while of the sodium and magnesium sulphate plants can withstand as much as 0.50 per cent. Observations upon the growth of alfalfa in the Roswell soils showed that it was just able to grow when from 0.40 to 0.50 per cent of alkali was present. The figure 0.50 has been taken as the maximum limit, and though plants are able to grow with this amount of salt in a soil the growth is uncertain and light, in fact 0.25 per cent damages crop growth to a great extent. This range is, therefore, taken as the danger limit.

The action of soluble matter within a soil upon the growth of plants is very complex and to a great extent not well understood. It is a fact of common note that a *little* alkali makes crops grow better. There is danger in this little alkali, however, for if the amount increases ever so little beyond the point where plants grow better, there is noted a decrease in production and the productivity of these soils may be considered dependent upon the per cent of alkali present. The fact has been noted that with 0.25 per cent of alkali in the top foot of soil the crop production is decreased. This decrease becomes more and more marked until the plants refuse to grow. The limit of growth may be considered 0.50 per cent. Occasional cases have been noted elsewhere where crops would live with more alkali present, but in the Pecos Valley, soils, with one-half of 1 per cent alkali, are entirely unproductive.

cies of soil and the result multiplied by the cell factor, giving the

U.S. DEPT OF AGRICULTURE
DIVISION OF SOILS
MILTON WHITNEY, CHIEF

ALKALI MAP

NEW MEXICO
ROSWELL SHEET

LEGEND

-.25
Less than
.25 per cent.

.25-.5
.25 per cent.
to .50 per cent.

.5+
Over .50 per
cent.
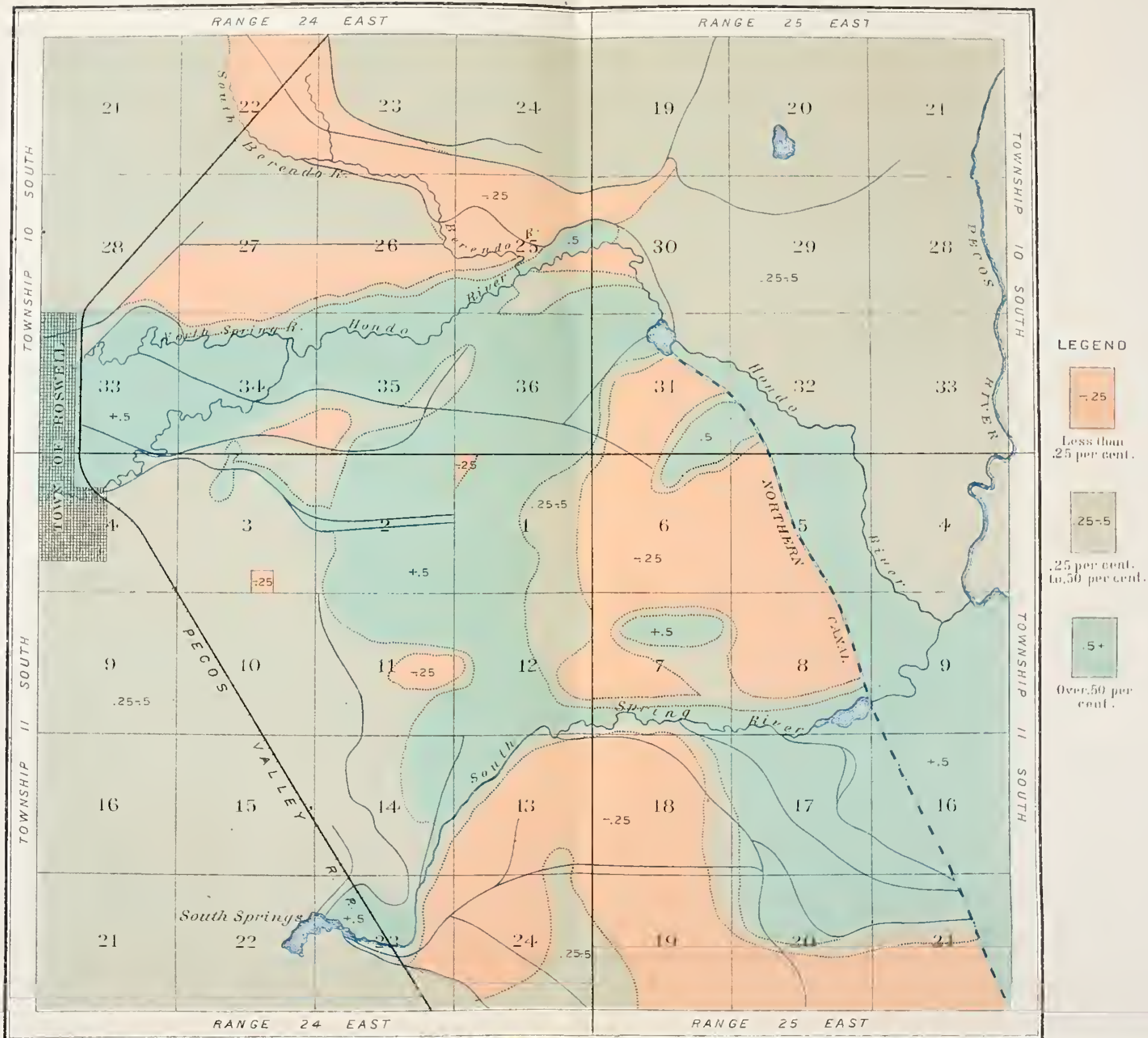
Surveyed by
Thos H. Means and
Frank D. Gardner
Condition June. 1899

LITH BY A HOEN & CO. BALTIMORE MD

Scale 1 in = 1 mile

Edition of 1899

H Doc 399 56 1

with one-half of 1 per cent alkali, are entirely unproductive.

Plants of different species are able to withstand different amounts of alkali, and the resistance of the same plant to alkali varies in different stages of its growth. In the Roswell area afalfa was found sickly and dying with a little over 0.40 per cent alkali in the soil, while in other stages of its growth isolated plants have been found growing in a soil containing more than 0.75 per cent alkali. Young apple trees showed signs of distress with a little over 0.30 per cent, while sugar beets grew with something over 0.50 per cent.

The action of soluble matter upon plant growth varies with the osmotic pressure of the solution in the plant tissues. This fact has been experimentally demonstrated by Slosson and Buffum of the Wyoming Experiment Station. Since the osmotic pressure varies with the concentration of the solution, the mere statement of the total percentage of salt within a soil determined chemically does not give a true idea of the osmotic pressure of a solution. The percentages as given in this report and in all reports of the Division of Soils are based upon the dry weight of the soil and are the amount of alkali dissolved by the water when the soil is saturated.

The method for salt determinations as used in the field work of the Division of Soils has been described in previous publications, but a short sketch of the method will be given here for the intelligent consideration of the results.

Samples of soil are collected with a 1½-inch soil auger with an extension handle long enough to bore 20 feet. The samples are usually taken in 1-foot sections and the alkali determined in each foot of depth. The soil as collected is thoroughly mixed upon a clean piece of oilcloth. A portion of the mixed sample is saturated with distilled water and packed in a hard-rubber cell of a capacity of about 50 c. c. with two metal sides. The electrical resistance of this saturated soil is taken by a Wheatstone bridge. The temperature is then taken by inserting a thermometer in the soil in the cell. This constitutes the field work. In the laboratory a number of typical samples of the alkali in the soil are analyzed and a solution of salt corresponding in relative composition to the average of these analyses is made. By varying dilutions of this solution the per cent of salt is ascertained for each 5 or 10 ohms difference in resistance. The per cent of water of saturation for each type of soil is then determined by saturating the soils in the same manner as done in the field and making gravimetric moisture determinations. Then by determining the weight of the wet soil the cell will hold, the number of cubic centimeters of the soil moisture in the cell filled with saturated soil may be calculated. Knowing the number of cubic centimeters of soil moisture contained in the cell full of saturated soil, the cell factor, or the figure by which the resistance of that amount of solution must be multiplied in order to give the specific resistance, can be found from the known constants of the cell. The resistance obtained in the field is multiplied by the figure 0.55 to correct for the resistance offered by the insoluble, nonconducting particles of soil and the result multiplied by the cell factor, giving the

specific electrical resistance of the solution around the soil grains. The per cent of salt corresponding to the specific resistance is determined from the solution made up from the chemical analyses of the field samples. This percentage, multiplied by the per cent of water in the saturated soil, gives the per cent of alkali in the dry soil.

In the field work borings are taken at frequent intervals and the salt content determined for each foot of depth. These percentages are plotted on base maps and lines drawn separating the three conditions of the soil respecting alkali. These three conditions are shown in the alkali map by different colors.

The maps as presented may be taken as an indication of the condition of the soil during June, 1899. For the construction of the maps the salt content of the soil to a depth of 5 feet was considered.

The area of Pecos loam is seen to be colored to indicate between 0.25 and 0.50 per cent alkali. This soil at every point examined within the area of the map was found to contain more than 0.25 per cent of alkali within the upper 5 feet. The porosity of this soil, however, would enable most of this salt to be immediately washed out upon the application of irrigation water, as has been seen in a number of places where small tracts of this upland soil were cultivated around Roswell.

The areas on the salt map showing from 0.25 to 0.5 per cent of salt are susceptible of a much greater range of conditions than are indicated by the range in salt content to the depth of 5 feet. Crops may make a moderate growth on any or all parts of this class of land, and there are places near the lower limit, undoubtedly, where the conditions are excellent at the present time, because the salts are so distributed that only small amounts are contained in the first and second foot, while a sufficient amount occurs below this to bring the average up to 0.25 per cent or more.

This condition, while giving excellent results at present, is dangerous, because the salts are liable to move toward the surface unless good underdrainage is provided.

As we approach the upper limit on this class of land the other extreme may be found to exist, i. e., an accumulation of salts at the surface in sufficient amount to kill all crops, and yet the quantity of salts be sufficiently small in the lower depths to bring the average for 5 feet below 0.5 per cent.

The Problems of the Roswell Area.

It has been shown under the discussion of the soils that the accumulation of the alkali salts in the surface of the soil is in all cases due to lack of drainage. The salts which are present now near the surface were once buried at such a depth as to be of little or no damage to plants, and this translocation has been brought about by irrigation. The water supply is good; therefore the salt must originally have come from the soil. Much of the land has already suffered from accumula-

tions of salt, so there are two important problems before the farmer: First, the prevention of further damage from seepage water and alkali salts; second, the reclamation of the lands already damaged or abandoned.

Roswell is situated in a large grazing country, and the principal industry is cattle and sheep raising. The agriculture is largely supplementary to the range. Alfalfa is the principal crop. There is, however, a growing tendency toward fruit raising on the part of some of the farmers. The local demand for fruit is great enough at present to use all of the fruit produced, but there is danger of overstocking the local market, and thus necessitating the shipment to distant markets.

Situated as it is, there is no question but that cattle and sheep will prove the most profitable industry toward which the farmers may turn. The success of the Roswell community is to be attributed to their realization of this fact. Since alfalfa offers the most ready forage crop, the soil should be in the best condition for its growth. One of the most essential conditions of a soil in an alfalfa field is good drainage. Alfalfa roots penetrate deep into the subsoil, and as soon as standing water is encountered their roots cease to grow. If drainage keeps the level of standing water down, the success of the crop is insured. Drainage also removes and insures no further damage from alkali.

THE HAGERMAN AREA.

GEOLOGY AND TOPOGRAPHY.

The Hagerman area, or Northern Canal system, lies about the center of the basin formed by the ancient obstructions in the Pecos River about Seven Rivers. The Roswell area lies near the northern end of the same basin. This basin, cut out of the Red Beds or Permian strata, is more or less filled with sediment derived from these rocks. The Red Beds contain crystals of gypsum scattered throughout their sands and gravels, and, interstratified with the beds of sand and clay, heavy, massive saccharoidal gypsum. It is to the solution and redeposition of this gypsum that the gypsum of the soils of the Roswell area is mainly due, though this gypsum in the soils may in part be from mechanical sedimentation.

The Hagerman area lies along the terraces cut by the Pecos River in the sediments of the old lake. The action of the Pecos has been aided by the streams entering from the west, notably by the Felix and Peñasco. The terraces are very imperfect, the land sloping from the edge of the river channel gradually upward to the west. On the east side the Pecos is bounded by high bluffs.

SOILS.

The soils of the Hagerman district correspond very nearly to the soils of the Roswell area. On the lowest lands lying close to the Pecos River dune sands and sandy loams form the predominating soil types. These are usually well drained from their nearness to the river channel, though occasionally, even when apparently in the most favorable

conditions, these lands are found wet and in need of drainage. On the level lands immediately around Hagerman, the soil is heavy and corresponds very nearly to the Roswell loam. Around this are areas of gypsum soil, which is exposed in drains to the south of Hagerman. The discussion of the cultivation of this gypsum land will be deferred until it is considered under the Carlsbad area, where it is more typically developed.

Upon the uplands of the Hagerman area and above the canal the Pecos loam, similar to the upland soil at Roswell, is typically developed. This area of soil is a continuation of the Roswell area. A soil map has not been drawn of the Hagerman area, as a short time only was spent in reconnoissance of the soils. The great similarity of this district to the Roswell and Carlsbad soils, however, will enable the conclusions drawn from them to be readily applied to the Hagerman conditions.

THE WATER SUPPLY.

The Northern Canal heads in a dam across the Hondo River directly east of Roswell. This dam collects and directs into the canal the unused and waste water from the Berendo and North Spring rivers, also from the Hondo in times of flowing in that stream above Roswell. A great deal of seepage and drainage water is collected, which, together with the salt from the Berendo water, renders the Northern Canal water salty. At the point where the Northern Canal crosses the South Spring River a second diverting dam collects the water of that stream. This also contains quantities of seepage and drainage water. The average condition of the Northern Canal water is shown by the following analysis by Prof. E. M. Skeats, of Carlsbad, N. Mex.

	Parts per 100,000.
NaCl	65
CaCO₃	17
CaSO₄	51
MgSO₄	25
K₂SO₄ } Na₂SO₄ }	23
Silica, alumina, and iron	2
Water of crystallization	19
Total solids	202

Of these salts calcium carbonate, calcium sulphate, the silicon, iron, and alumina compounds, with much of the water of crystallization, amounting in all to 89 parts, may be disregarded, since upon the evaporation of the water these compounds crystallize out and do not collect in the soil in sufficient quantity to be of harm to vegetation. Thus the harmful salts of the water are present in the proportion of 113 parts of salt to 100,000 of water.

UNDERGROUND WATER.

The wells above the canal are from 60 to 100 feet deep, with water at about 60 feet. The water in all of these wells is good, containing about
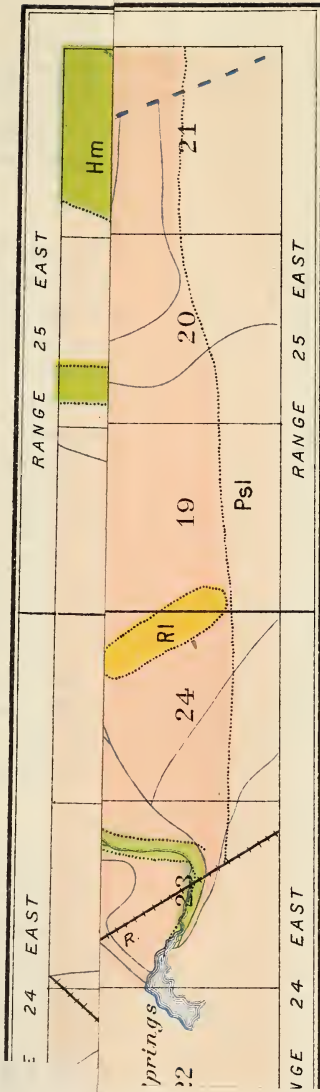
SOIL MAP

NEW MEXICO
ROSWELL SHEET

Scale 1 in = 1 mile

Edition of 1899

LITH. BY A. HOEN & CO. BALTIMORE MD.

H Doc. *399* 56 1

RANGE 25 EAST

RANGE 25 EAST

24 EAST

24 EAST

Hm

Rl

Psl

U.S. DEPT. OF AGRICULTURE
DIVISION OF SOILS
MILTON WHITNEY, CHIEF.

SOIL MAP

NEW MEXICO
ROSWELL SHEET

SOIL PROFILE

(6 feet deep)

Pecos
sandy loam

Ssc

Sc

Roswell
sandy loam

Ssc

Sc

C

Roswell
loam

Sc

Scc

C

Hondo
meadows

Scc

C
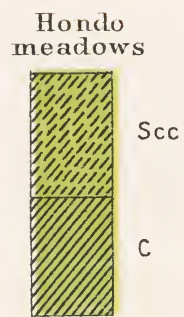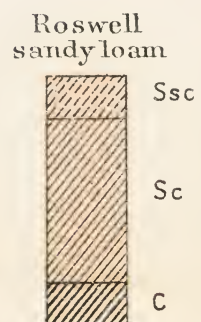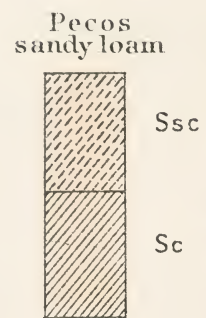
LEGEND

Ssc Sandy loam
Sc   Loam
Scc Clay loam
C   Clay

LEGEND

Psl

Pecos
sandy loam

Rsl

Roswell
sandy loam

Rl

Roswell
loam

Hm

Hondo
meadows

RANGE 24 EAST

RANGE 25 EAST

TOWNSHIP 10 SOUTH

TOWNSHIP 10 SOUTH

TOWNSHIP 11 SOUTH

TOWNSHIP 11 SOUTH

South Berendo R.

Berendo R.

Psl

Hm

North Spring R.   Hondo   River

TOWN OF ROSWELL

Hm

Rsl

Rl

Rsl

PECOS VALLEY

Psl

NORTHERN CANAL

Hondo   River

PECOS RIVER

Rsl

South   Spring   River

Psl

Rl

Rsl

South Springs

R.R.

RANGE 24 EAST

RANGE 25 EAST

21 22 23 24 19 20 21
28 27 26 25 30 29 28
33 34 35 36 31 32 33
4   3   2   1   6   5   4
9   10 11 12 7   8   9
16 15 14 13 18 17 16
21 22 23 24 19 20 21

Surveyed by
Thos H. Means and
Frank D. Gardner
1899.

LITH. BY A. HOEN & CO. BALTIMORE MD

Scale 1 in = 1 mile

Edition of 1899

H Doc 399 56 1

35 parts of soluble matter per 100,000. Of the land below the canal, part of it has already become so wet that underdrainage is necessary. Around the town of Hagerman water is found in places as near the surface as 3 feet. During the four years during which irrigation has been practiced the entire character of the vegetation around Hagerman has been changed from grama and other prairie grasses to salt grass. The change has been brought about almost entirely by underground seepage waters and alkali.

ALKALI OF THE SOILS.

The condition of the soils of the Hagerman area correspond exactly to the conditions existing at Roswell. The cause of the present conditions, however, includes one factor which was noted as unimportant in the Roswell area; that is, the amount of alkali in the irrigation water. The application of each acre-foot of Northern Canal water adds 3,000 pounds of salts to the soil. Such salts, if allowed to accumulate by evaporation of the water, would soon so impregnate the soil with alkali that crops would not grow. Allowing $2\frac{1}{2}$ acre-feet per year, in two years 15,000 pounds of soluble matter would have accumulated, or enough to prevent profitable cultivation, provided all of the salt was retained by the surface foot of soil. This rapid accumulation may easily be prevented by washing the accumulated salts from the previous irrigation down into underground drainage. Another successful method is to grow soil-shading crops which prevent the rapid evaporation from the surface of the soil, so that less water is needed in irrigation. Cultivation offers the most effective method of preventing evaporation from the soil's surface, and this should be carefully followed out in the growth of all crops which allow cultivation.

PROBLEMS OF THE DISTRICT.

The problems of the Hagerman district are very similar in character to the problems of the Roswell district. The accumulation of alkali salts must be prevented, and the excess already present must be removed. The leakage from canals and laterals, particularly in the case of water containing alkali salts, is one of the most potent sources of trouble. The loss from the canal in running through the sandy and gravelly soils is great. In the case of the main canal 1 cubic foot per second is lost for every mile. This water, seeping under the ground, gradually fills up the subsoil until capillary force lifts the water to the surface, where it evaporates leaving the alkali.

CARLSBAD AREA.

GEOLOGY.

The Carlsbad area lies entirely in Eddy County, New Mexico, along both sides of the Pecos River. The irrigation district lies in a basin cut off on the north by a canyon, through which the Pecos runs, and on

the south by canyons and rough country from below the Black River to the Texas line. This basin is undoubtedly the site of an ancient lake, bounded on the west by the foothills of the Guadalupe Mountains, on the east by the scarp of the Staked Plains. The entrance to and exit from this basin were through narrow gorges cut in the hard carboniferous rock of the foothills. The sediments form the present soils of the district, modified to a great degree by the Pecos and the drifting action of the wind. The elevation of the country, or more likely the cutting away of the dam below Black River, placed the Pecos in position to commence the removal of the lake sediments. The river has begun the cutting and has already worn down to its hard rock over part of the district, and has commenced meandering in its bed, forming broad and treacherous sand bars. At other points in its course the Pecos has worn down to the conglomerate which lies at the base of the lake sediments.

The water supply of the Carlsbad area is derived entirely from the Pecos River. The original plans for irrigation contemplated taking the water direct from the river with a storage reservoir 6 miles above Carlsbad, with a capacity of 7,000 acre-feet. The situation of the dam is in a canyon with limestone walls, offering a natural abutment for the ends of the dam. This storage reservoir proving inadequate, a second reservoir was constructed 17 miles above Carlsbad, near Seven Rivers. This dam forms a lake 8 miles long and of an average width of $1\frac{3}{4}$ miles, with a storage capacity of 140,000 acre-feet.

SOILS.

Map 4 accompanying this report shows the soils of the Carlsbad area. Four distinct types of agricultural soil have been recognized and named, each type being different in its relation to irrigation waters and alkali and to vegetation. These types are as follows:

1. Pecos sands.
2. Pecos sandy loams.
3. Pecos conglomerate soil.
4. Gypsum loam or "yeso."

THE PECOS SANDS.

Along the Pecos River, filling up the tortuous bends of its course, are areas of sands blown about by the winds. The characteristic vegetation of mesquite, yucca, and canaigre in a great measure prevent the drifting of these sand dunes. The mesquite forms small dunes around its roots, and as the dunes build up the mesquite extends its roots, keeping on top of the dunes. In this way dunes 8 to 10 feet high are formed with mesquite growing on the top. This dune sand is composed of rounded grains of quartz with smaller quantities of gypsum and limestone. The texture of the dune sand is shown in the following table:

PLATE III.

SAND DUNES WITH CHARACTERISTIC VEGETATION OF MESQUITE AND CANAIGRE, NEAR CARLSBAD, N. MEX.

These sand dunes when leveled down and put under irrigation make good truck land.

S.

24   19

25   30

36   31

1   6

12   7

P

6 f

Pec

13   18

Pc

8

T. 24 S.

29 E.

n of 1899.

e 1 in = 1 mile

1

SOIL MAP

NEW MEXICO
CARLSBAD SHEET

SOIL PROFILE
(6 feet deep)

Pecos sand
S

Pecos sandy loam
Ssc   Sc

Pecos conglomerate
Ssc/Gr   Congl

Pecos gypsum
Ssc   Gyp
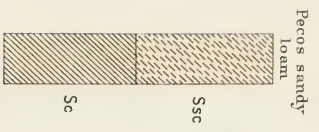
LEGEND

S   Sand
Ssc   Sandy loam
Sc   Loam
Gr   Gravel
Gyp   Gypsum
Congl   Conglomerate

LEGEND

Pecos sand
Ps

Pecos sandy loam
Psl

Pecos conglomerate
Pc

Pecos gypsum
Pg

Scale 1 in=1 mile

CARLSBAD

OTIS

FLORENCE

MALAGA

Lake Avalon

DAM

East Side Canal

Pecos River

Black River

Edition of 1899
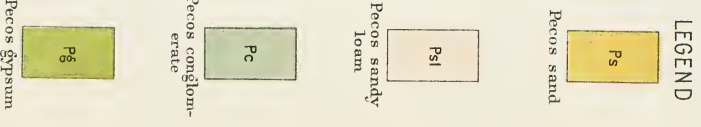
Mechanical analysis of dune sand.

Diameter.	Conventional names.	4064. Carlsbad, 2 miles N W., 0 to 6 inches.
Millimeter.		*Per cent.*
2 to 1	Gravel	0. 00
1 to 0. 5	Coarse sand..........	. 00
0. 5 to . 25	Medium sand..............	. 22
. 25 to . 1	Fine sand	70. 25
. 1 to . 05	Very fine sand.............	21. 50
. 05 to . 01	Silt.......................	2. 70
. 01 to . 005	Fine silt..................	. 43
. 005 to . 0001	Clay	4. 22
Loss at 110° C		. 43
Loss on ignition		. 35

This type of sandy soil is from its texture well adapted to truck farming and root crops. Melons, potatoes, and small fruit grow well on this soil. It forms the soil of La Huerta, that part of Carlsbad north of the Pecos River and immediately adjoining the town. There are narrow strips of this soil found along the river as far south as the area was examined. Such a soil is not apt to be rich in plant food, but in the forcing of fruit and early vegetables this is not so necessary as ease of cultivation.

The virgin Pecos sand contains very little alkali. Examinations were made at points all over the area of the portion mapped out, and in no case was natural accumulation of alkali found. The alkali profile, in Figure 2a, shows the per cent of alkali in two typical soils, one never irrigated and the other irrigated. It will be seen that the irrigated soil on the average carries a little more alkali than the virgin soil.

THE PECOS SANDY LOAM.

This is the most important type of soil in the Carlsbad area and covers the greater part of the irrigable land under the Southern Canal. This loam is very similar in character and texture to the Pecos sandy loam at Roswell.

The accompanying table shows the average texture of the soil.

Mechanical analyses of Pecos sandy loam soils.

Diameter.	Conventional names.	4067. ¼ mile S. Otis, N. Mex., 0 to 12 inches.	4068. 1½ miles S. Otis, N. Mex., 0 to 12 inches.
Millimeters.		*Per cent.*	*Per cent.*
2 to 1	Gravel	0. 00	0. 00
1 to 0. 5	Coarse sand...............	Trace.	Trace.
0. 5 to . 25	Medium sand..............	1. 32	1. 65
25 to . 1	Fine sand..................	10. 20	12
. 1 to . 05	Very fine sand.............	36. 30	41. 45
. 05 to . 01	Silt	19. 10	10. 27
. 01 to . 050	Fine silt..................	3	10. 45
. 005 to . 0001	Clay	18. 65	18. 72
Salts dissolved in 1½ liters of water, used in mechanical analyses........		4	2
Loss at 110° C.......................		2. 60	2. 67
Loss on ignition......................		4. 70	2. 45

The mechanical analyses of 4067 and 4068 represent typical soil from the Pecos sandy loam. These soils in the field appear much lighter in texture than the mechanical analysis would indicate. A microscopical examination of the soils was made to see the cause of this. Under the microscope a great many particles were found to consist of little conglomerates of clay cemented by lime. These particles upon shaking in the mechanical analysis gradually disintegrated, forming a soil which contained 32 per cent of clay. Since a mechanical analysis made in

a. In Pecos sand.
 .... Before irrigation.
 —— After irrigation.

b. In Pecos sandy loam.
 —— Original soil.
 ...... Irrigated soil.
 —·—·— subirrigated soil.
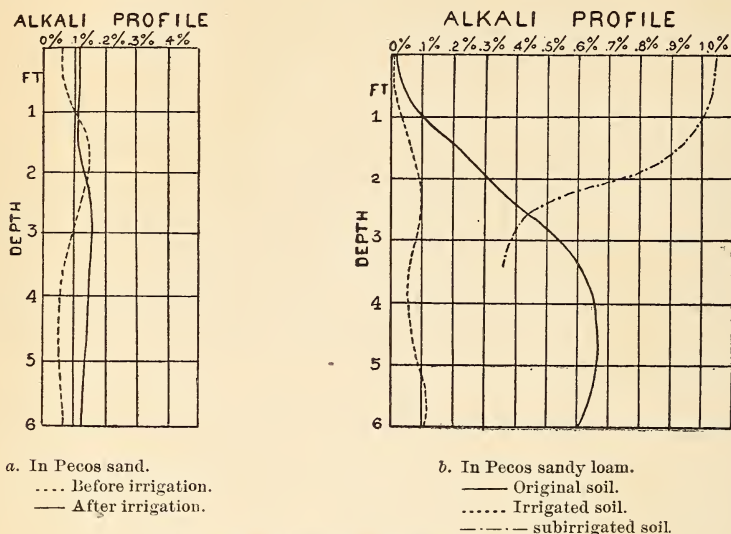
FIG. 2.—Diagram showing salt content to depth of 6 feet.

this way did not represent true field conditions analyses were made with only enough shaking with water to wash off the loose clayey particles. Also in soils containing gypsum and lime, the water used for the mechanical analysis dissolved a quantity of the gypsum and lime. This amount is indicated in the table as soluble in water, but must not be taken to represent the per cent of alkali salts.

In the field the breaking down of the particles is observed in spots continuously wet, and even with a normal amount of moisture the soils have become a little heavier by this disintegration. In some parts of the area this disintegration of the soil has gone on since irrigation commenced, and now we have irrigated soils which are heavier than non-irrigated soils situated under the same conditions.

The alkali profile given in figure 2b shows the per cent of alkali salt in the soil under three conditions: (1) The virgin soil; (2) the soil after irrigation, where drainage is good; and (3) the soil where irrigated when the drainage is poor or when subirrigated. The texture profile on the soil map shows the soil to be composed of nearly all (93 per cent) sand to a depth of 6 feet. Situated as these sands are, along the banks of the river, the drainage is normally good and the salt, which originally is found in the subsoil, is readily leached out and
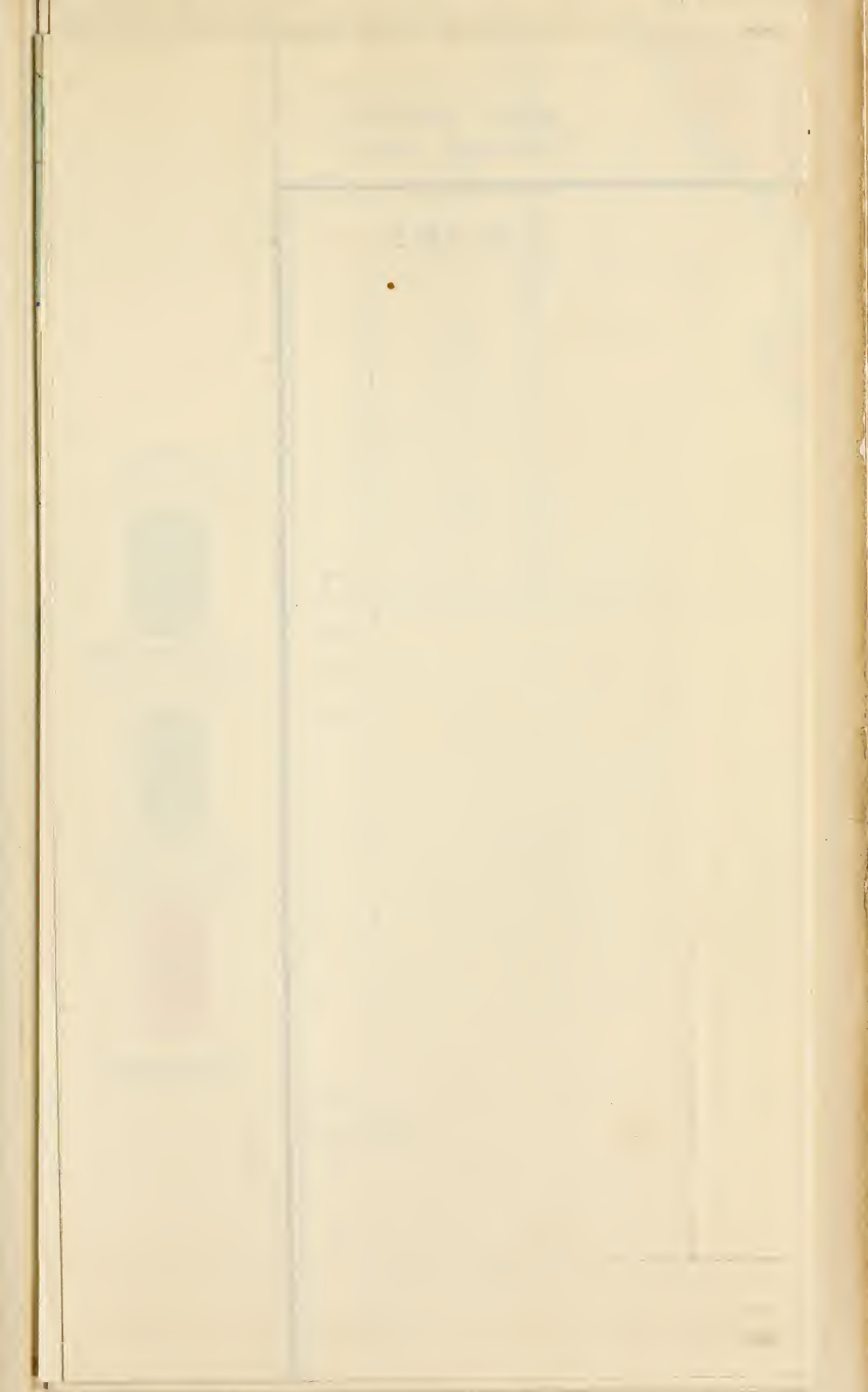
U.S. DEPT OF AGRICULTURE
DIVISION OF SOILS
MILTON WHITNEY CHIEF

ALKALI MAP

NEW MEXICO
CARLSBAD SHEET

T. 24 S.   T. 23 S.   T. 22 S.   T. 21 S.

R. 26 E.   R. 27 E.   R. 28 E.   R. 29 E.

Surveyed by
Thos H Means and
Frank D Gardner
Conditions April–May 1899

Scale 1 in=1 mile

Edition of 1899

H Doc 399 56 1

Lake Avalon

CARLSBAD

OTIS

FLORENCE

MALAGA

Black River

Pecos River

East Side Canal

Hagerman Lateral
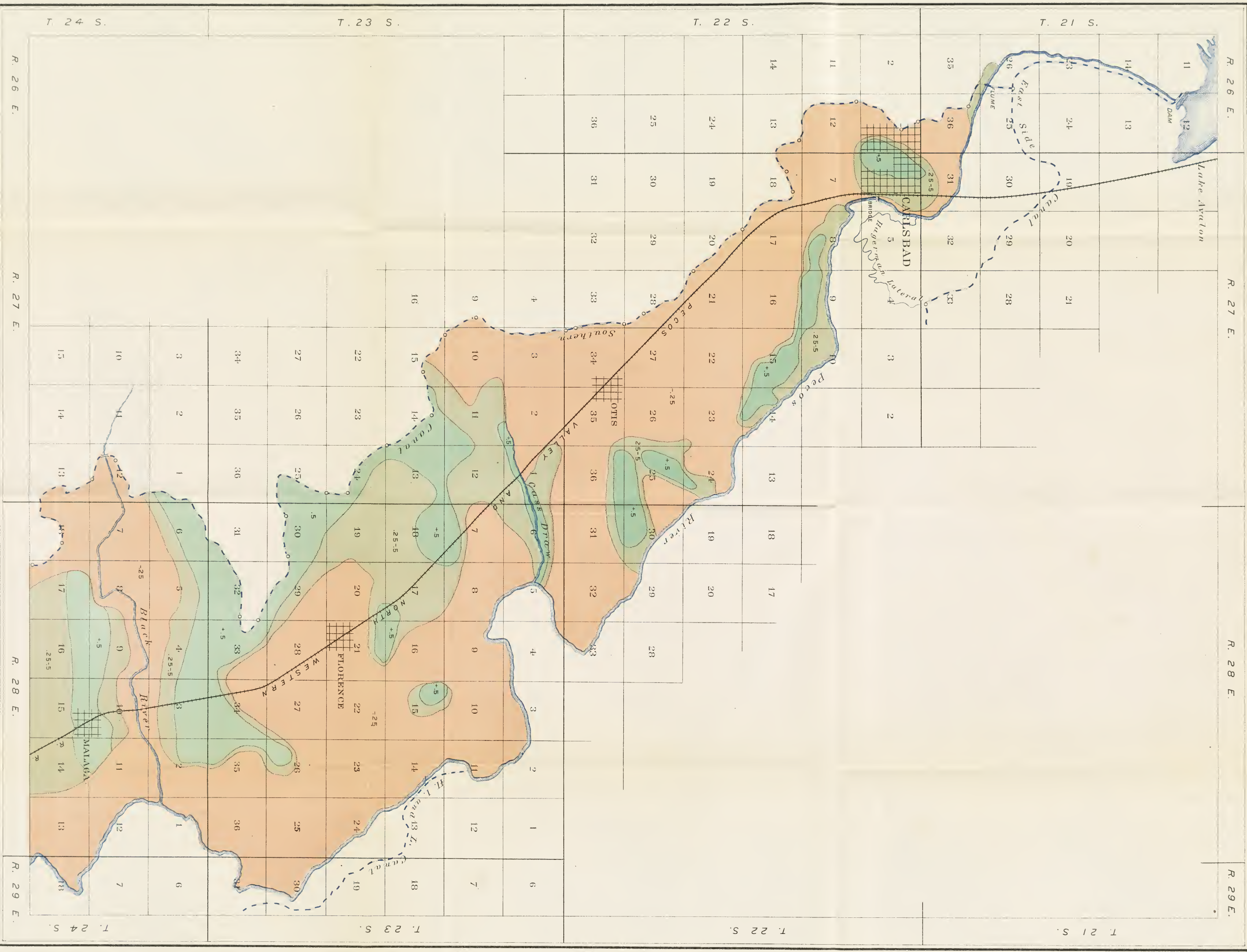
LEGEND

.25	Less than .25 per cent.
.25-.5	.25 per cent. to .50 per cent.
.5	Over 50 per cent.

carried away. Where this drainage is defective the evaporation from the surface is sufficient to rapidly concentrate the soil solutions and alkali salts accumulate at the surface. Such a state of affairs is found along the foot of the gravel bluffs, in secs. 8, 9, 10, 14, and 15, of 22 S., R. 27 E. (See map 5.) Here the water in seeping out from the conglomerate bluffs has swamped an area of land and the rapid evaporation of the water is swiftly producing an alkali flat.

The Pecos sandy loam contains about 20 per cent of carbonate of lime. So much lime is objectionable to a great many plants, but fortunately the class of plants grown in the Pecos Valley are tolerant of lime. The humus content of the soil is low, as is true of many of the arid climate soils. Since the humus is the principal element of nitrogen, this element is perhaps the element most needed in the Pecos Valley soils.

The plowing under of alfalfa is found to be of great benefit to sugar beets, due to the addition of the nitrogenous organic matter of the alfalfa. The practice of plowing under alfalfa has not been general, since the cost of seeding and starting alfalfa is heavy. The first year's crop is not sufficient to pay for the cost of planting. There are other leguminous crops which, without doubt, could be grown in the valley, and could be turned under with profit.

The question of fertilizing, either with green manures or chemical fertilizers, is one which farmers of the West are very loath to consider. Western soils are usually rich soils, but in some districts even the virgin soils are poor. Particularly is this true of soils in the true arid regions, where the native vegetation is scanty and the humus content of the soils very low. The yield of sugar beets per acre upon the Pecos loam averages less than 5 tons per acre. This low yield is due partly to lack of proper plant food within the soil. No experiments, so far as known, have been conducted on the effect of fertilizers other than alfalfa upon the growth of beets or other crops. This defect in the soil is realized by the farmers at present, and improvement in their methods of handling the soils is looked for in the near future.

PECOS CONGLOMERATE SOIL.

Underlying the Pecos sandy loam throughout the area examined is found a bed of gravel or conglomerate. This conglomerate is exposed over many points in the area, and whenever so exposed its disintegration gives rise to a gravelly soil. This loose material is usually 2 feet deep, underlaid by gravel or conglomerate. The table following illustrates the texture of the soil. No. 4069 contained 19.3 and 4070 contained 26.1 per cent of coarse gravel.

H. Doc. 399——5

Mechanical analysis of Pecos conglomerate soil.

Diameter.	Conventional name.	4069.	4070.
Millimeters.			
2 to 1	Fine gravel	Trace.	Trace.
1 to 0.05	Coarse sand	1.20	1.11
0.95 to .25	Medium sand	1.80	1.97
.25 to .1	Fine sand	12.51	12.88
.1 to .05	Very fine sand	45.77	39.81
.05 to .01	Silt	12.91	17.66
.01 to .005	Fine silt	3.43	3.46
.005 to .0001	Clay	17.22	18.22
Loss at 110° C.		2.21	2.37
Loss on ignition		2.99	4.08

Presenting as it does such a large percentage of gravel, this soil is difficult to cultivate. Water readily leaches through it, and its irrigation would require large heads of water to cover short distances. Very little of this gravelly land has been cultivated. The area is seen to be large, and as land becomes scarcer and more valuable there will no doubt be a demand for this gravelly soil.

The ready penetration of the water in this soil makes low-lying areas of it uncertain, for water seeping up from below through the conglomerate soon swamps the overlying soil.

The canal over part of its course runs through the conglomerate. At these points quantities of water seep out of the bed and through the conglomerate to appear lower down. The alkali flats in several sections have been formed in this way from the seepage water out of the conglomerate bluff into the sandy soils along the river bottoms.

This permeability of the conglomerate offers one of the great sources of danger from seepage water.

FIG. 3.—Diagram of orchard showing depth to standing water.

Though it offers a ready natural underdrainage for part of the upland, it is in the same way a great source of damage to the low-lying lands. Draws and flats adjacent to

CONGLOMERATE IN PECOS RIVER BED.

This layer of conglomerate extends under nearly all of the soils of the Carlsbad area, affording good drainage to some soils and being an element of danger to others differently located.

the hills of conglomerate receive as seepage water the drainage from the upper lands.

Figure 3 shows the depth to standing water in an orchard near Carlsbad being injured by seepage water and alkali coming from under the conglomerate. The arrow shows the direction of the underground drainage toward the Pecos River. The surface of the orchard is nearly level and about 20 feet above the river. This shows the influence of the good drainage along the river bank, in lowering the level of the standing water.

Figure 4 shows the soluble salt content of the surface foot in the orchard and the influence of the good drainage along the Pecos River. The relation of these lines to the drainage lines in figure 3 is very apparent.

GYPSUM LOAM OR "YESO."

The soil map shows a large irregular-shaped area of gypsum soil north of Black River and another area south of Black River, around Malaga.

This gypsum or "yeso," as the native Mexicans term it, possesses marked peculiarities which merit a careful study.

The material is composed of nearly pure gypsum in a granular form. When dry it is hard and compact, but upon wetting it absorbs water about as readily as a lump of sugar and breaks down into a soft mass which is very pervious to water.

Mechanical analyses of this material are very indefinite because the particles are so

FIG. 4.—Diagram of orchard showing soluble salt content of surface foot.

soft that they break up by agitation with water. The area mapped as gypsum soil does not everywhere have the gypsum on the immediate surface, but in nearly all places is covered with a thin layer of loam, derived from the decomposition of the gypsum or deposition by wind and water of other material. This loam varies in thickness from a fraction of an inch to 3 feet in depth.

The composition of the gypsum loam is shown in the accompanying table:

Mechanical analyses of gypsum loam soils.

Diameter.	Conventional names.	4071.	4074.
Millimeters.		*Per cent.*	*Per cent.*
2 to 1	Gravel........................	....	....
1 to 0.5	Coarse sand	Trace.	....
0.5 to .25	Medium sand...............	2.26	2.58
.25 to .1	Fine sand	9.42	14.25
.1 to .05	Very fine sand.............	38.47	37.13
.05 to .01	Silt	12.67	13.95
.01 to .005	Fine silt...................	10.87	8.88
.005 to .0001	Clay	19.70	15.46
Salts dissolved in 1½ liters of water used in mechanical analyses........		1.90	2.34
Loss at 110° C...............................		3.03	2.80
Loss on ignition.............................		3.41	3.27

The most important physical property of the gypsum is its capillary power. When compared with another soil this property of the gypsum is remarkable. Wet spots have been observed in a field where on boring water could not be found within 6 feet of the surface.

A tube filled with the gypsum soil was placed with its lower end in water and the height to which the water rose was determined every day. The following table shows the results of the experiment:

Time.	Pecos gypsum, height in inches.	Pecos dune sand, height in inches.	Time.	Pecos gypsum, height in inches.	Pecos dune sand, height in inches.
15 minutes................	1½	6½	6 days	37½	....
45 minutes................	2¼	11½	7 days	40	....
1 hour	3	13	8 days	42¼	....
2 hours	5	14	9 days	44¼	....
6 hours	9½	17	10 days	46½	....
24 hours	17½	18¼	13 days	50½	....
2 days	24	19½	14 days	52	....
3 days	27¾	20½	15 days	53	....
4 days	32	20½	25 days	58	21

At the time the top of the tube was wet the water was slowly rising, and no doubt would have risen several inches higher. This great capillarity is of special importance and must be fully considered before reclamation by irrigation. The surface of the soil is kept moist all the time and the rapid evaporation from the surface causes the deposition of the alkali salts. It is undoubtedly this physical property which renders the cultivation of the gypsum soils so difficult in the Pecos Valley. The New Mexico Experiment Station has shown that, in itself, the gypsum is not harmful to plant growth, but in districts where water contains alkali salts the cultivation of the gypsum can not be recommended.

One of the most serious difficulties in the way of reclamation of gypsum lands would be their proper drainage. Canals, ditches, and laterals when passing through the gypsum are found to lose quantities of water by seepage, both lateral and downward. Cavities and underground channels are dissolved out in the gypsum, which makes it very

PLATE V.

A GYPSUM SOIL WITHOUT THE USUAL COVERING OF LOAM, NEAR FLORENCE, N. MEX.

This material looks like white alkali, but is quite free from this except where affected by seepage water.

difficult to drain the soil. Open drains have been seen in which the water would flow in from one side, directly across the drain, and out into the subsoil on the other side. The great depth from which water is raised by the gypsum would necessitate the placing of the drains deeper than usual. Open drains can not be used, for the gypsum erodes so easily that the drains are not easily controlled. The irrigation laterals on the gypsum area, if run on a steep grade, cut deep trenches and fill up the subsoil with the water which seeps from their sides and bottoms. Plate VI shows such a lateral, which has cut a trench in places 10 feet deep in the gypsum. The virgin gypsum carries small quantities of alkali salts in nearly all places examined, but at no point was an accumulation of alkali salts encountered. A very different state of affairs is seen after the gypsum has been irrigated. The top of the soil soon becomes crusted over and the growth of agricultural plants prevented. Even where not cultivated, but in the vicinity of ditches and irrigated fields, the subirrigation of the gypsum is so great as in a few years to destroy all vegetation which can not withstand quantities of alkali.

From our present knowledge of the subject, the cultivation of pure gypsum soils is to be discouraged in the Pecos Valley.

The Water Supply of the Carlsbad District.

The irrigation water of the Carlsbad district is obtained by storage of the Pecos water. It has been shown that the normal flow of the river is all from springs situated along its middle and lower courses in New Mexico. This water contains more or less alkali in solution all of the time, and in standing in reservoirs the evaporation from the surface serves further to concentrate the water. The evaporation in Lake McMillan has been found to be as much as $4\frac{1}{2}$ inches per week, and, though authentic records are not at hand, the evaporation from a water surface is estimated to be about 10 feet of water per year. This great evaporation from the surface of a large reservoir is a very important item in the engineering of a storage system for the southwest. Estimates by the engineer of the Southern Canal system at Carlsbad during the summer of 1899 showed that during several weeks of May and June the evaporation from the large reservoir exceeded the inflow from the Pecos by as much as 25 cubic feet per second. The inflow from the Pecos is at a minimum during the winter and early spring, and the evaporation during this time continues to concentrate the water, so that when the water is first needed for young, tender plants, such as sugar beets, it is in its worst condition. The first floods, which occur generally in May or June, bring down large quantities of salt which have accumulated in the salt drains of the upper Pecos. These floods seldom improve the condition of the water. Later floods furnish the purest water of the season, and it is upon these floods of pure water that the farmer should depend, if possible.

From analyses by Prof. E. M. Skeats, of Carlsbad, the condition of the water has been found to vary from 510 parts soluble matter in 100,000 parts of water found in the first floods, to 243 parts found in the later floods, with an average of 310 parts. Professor Skeats gives the following as the average composition of the soluble matter in the Pecos water:

	Parts per 100,000.
NaCl	98
CaCO$_3$	11
CaSO$_4$	130
MgSO$_4$	49
K$_2$SO$_4$	5
Silica, alumina, and iron	2
Water of crystallization, etc	15
Total salts	310

Of this it will be seen that 152 parts per 100,000 are salts likely to accumulate in the soil solutions and injure plants. The application of 2½ acre-feet of water would add 10,000 pounds of soluble salts to the soil, and, since 15,000 pounds can be taken as the maximum amount allowable in the surface foot of the soil, 1½ years only would be required so to fill the soil with alkali that agriculture would be unprofitable. This salt, however, is not all deposited in the surface foot, but is distributed in the soil as deep as the water penetrates, and if enough water is added to wet down to the level of standing water part of the salt left from the evaporation of the previous irrigation is washed away.

During June, 1899, a sample of the water from the main canal near Carlsbad was taken. A chemical analysis of this sample was made by Dr. Frank K. Cameron, chemist of this division, with the following result:

	Parts per 100,000.
CaSO$_4$	161.64
MgSO$_4$	2.16
Na$_2$SO$_4$	59.98
NaCl	168.16
	391.94
Undissolved after evaporation	43.28
Total salts	435.22

The water at the time this sample was taken was said to be so concentrated as to injure young sugar-beet plants. The osmotic pressure of a solution is the determining factor in its action toward plants; the water at this time contained about one-half as much salt in actual solution as could be endured by most plants. To this salt was added that already within the soil, so that the delicate rootlets were immersed
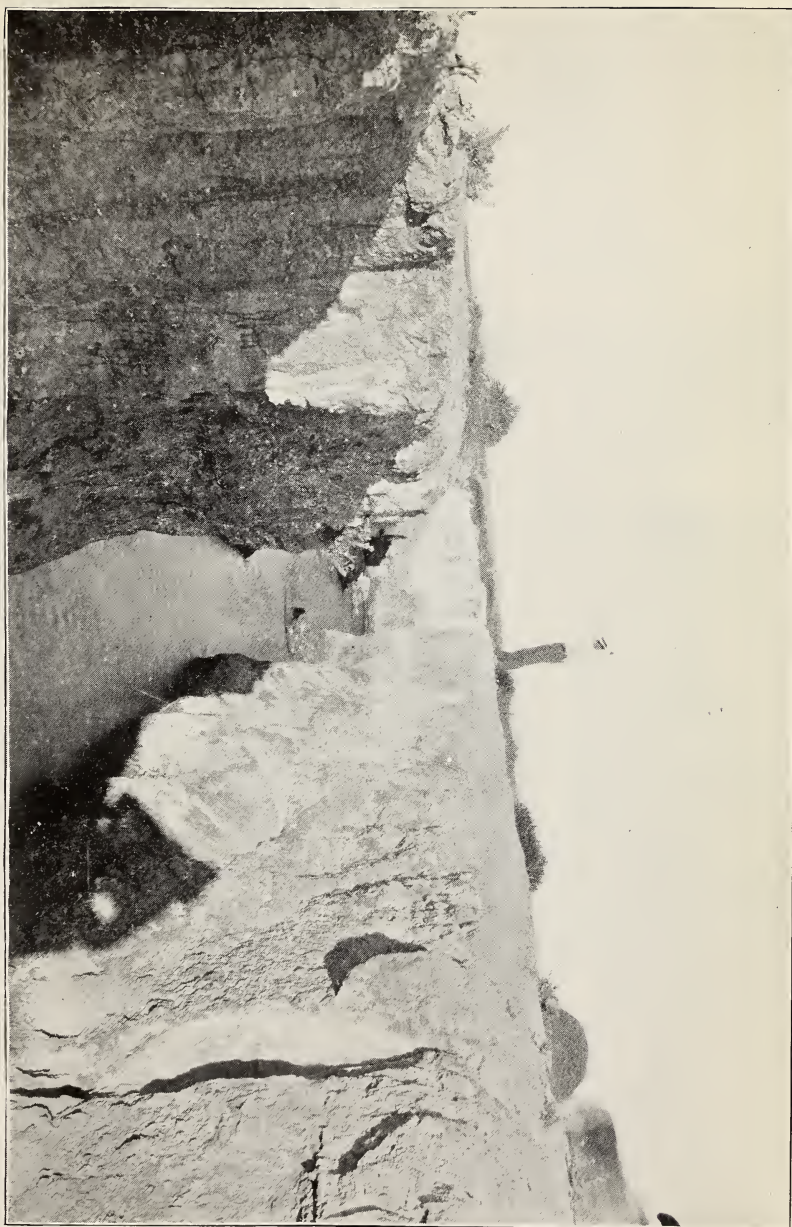
A LATERAL DITCH CUTTING DOWN INTO THE GYPSUM SOIL.

The gypsum is so soft and transmits seepage water so readily that it is to be avoided in irrigation work.
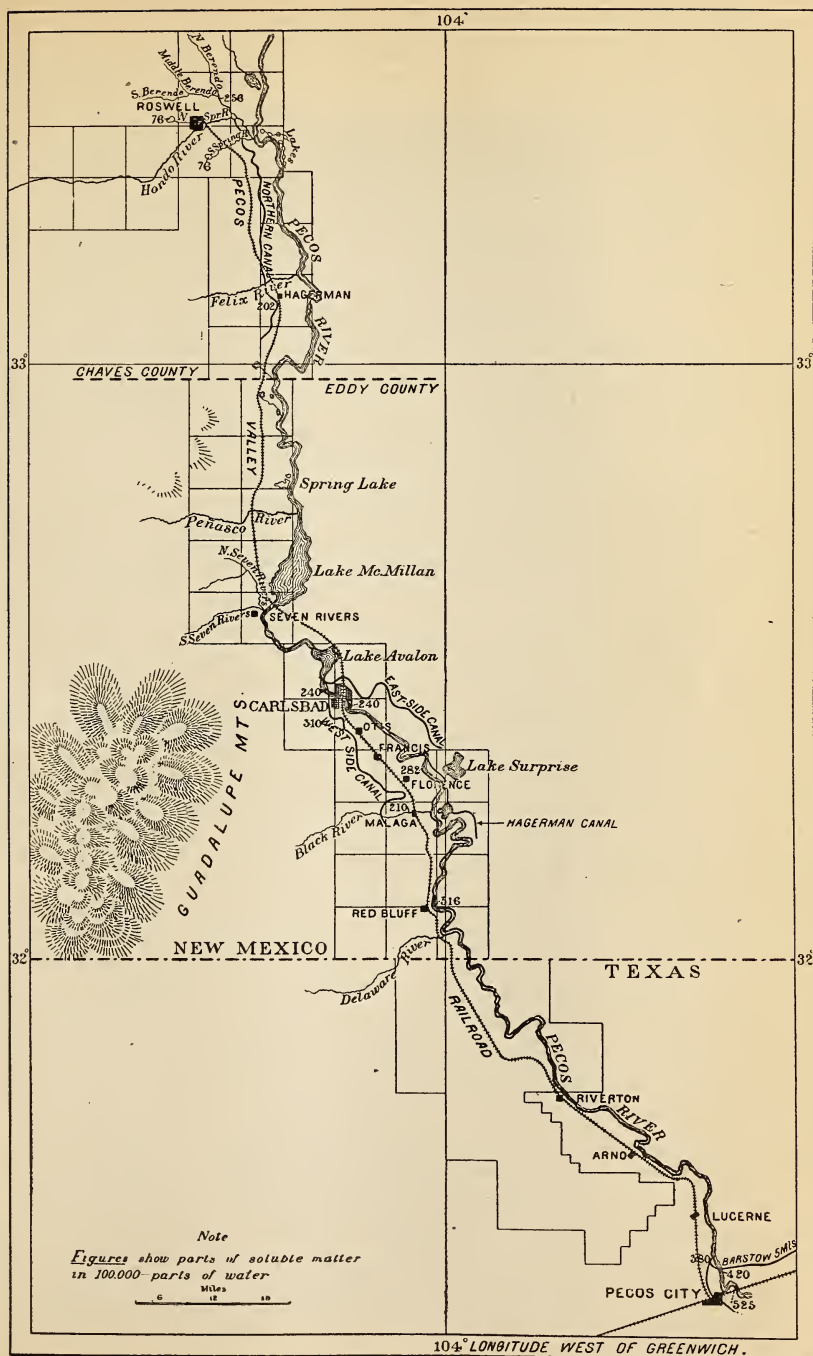
FIG. 5.—Sketch map of Pecos Valley, showing increase in salt content of water as it flows down the valley. (The figures show the salt content in parts per 100,000.)

in a solution almost as concentrated as they were able to stand. Under the intense heat of the sun of southern New Mexico this solution soon evaporates so much near the surface that it concentrates beyond the limit of plant growth. In the solution outside the rootlets the osmotic pressure becomes higher than the osmotic pressure inside the rootlets, and the plant dies of thirst though in the presence of plenty of moisture.

Figure 5 gives a graphic idea of the salt content of the water in different parts of the valley.

UNDERGROUND WATER.

One of the maps accompanying this report shows the depth to water, measured from the surface of the ground. The map indicates by the shades the three conditions of the land: (a) Water more than 10 feet below the surface; (b) water between 3 and 10 feet; (c) water 3 feet or less.

The general condition of the vegetation throughout the area watered by the Southern Canal system is not healthy. Crops are more subject to disease than is the case under similar conditions in humid climates. Sugar beets are subject to a root-rot; fruit trees suffer from something similar, and even alfalfa has a disease which attacks the roots. This unhealthy condition can be attributed to the condition of the irrigation water. Plants with their roots immersed in a solution of the concentration of the irrigating water from the Southern Canal are weakened and the germs of disease, which seem to be present in all of the soil, are enabled to attack the plant, weakening it further. This root disease is difficult to deal with, since the application of sprays to the roots is an impossibility. Some benefit has been claimed from the application of copperas around the roots of the trees.

The depth of wells over the greater part of the district was at least 40 feet originally; at present water can be found over nearly the whole of the irrigated land at less than 20 feet. In some of the wells which were dug 40 feet eight years ago water stands now at a depth of 5 to 10 feet during the irrigating season. In the winter, after the water has been taken out of the canals and laterals, the water slowly lowers in the wells. As soon as the water is turned in the main canal the level in the wells begins to rise, even before the irrigation commences on the lands around the wells. That the loss from canals and laterals is the greatest source of seepage water in irrigation districts is a fact which is coming to be generally recognized. There is without doubt much seepage water from overirrigated land, but the loss from constantly running canals and laterals far exceeds this. The loss from the canals of the Carlsbad district, while not great when compared with the loss of canals of other districts, is great enough to cause serious damage. The canal in crossing the beds of gravel and conglomerate loses appreciably by seepage. The following measurements of loss in
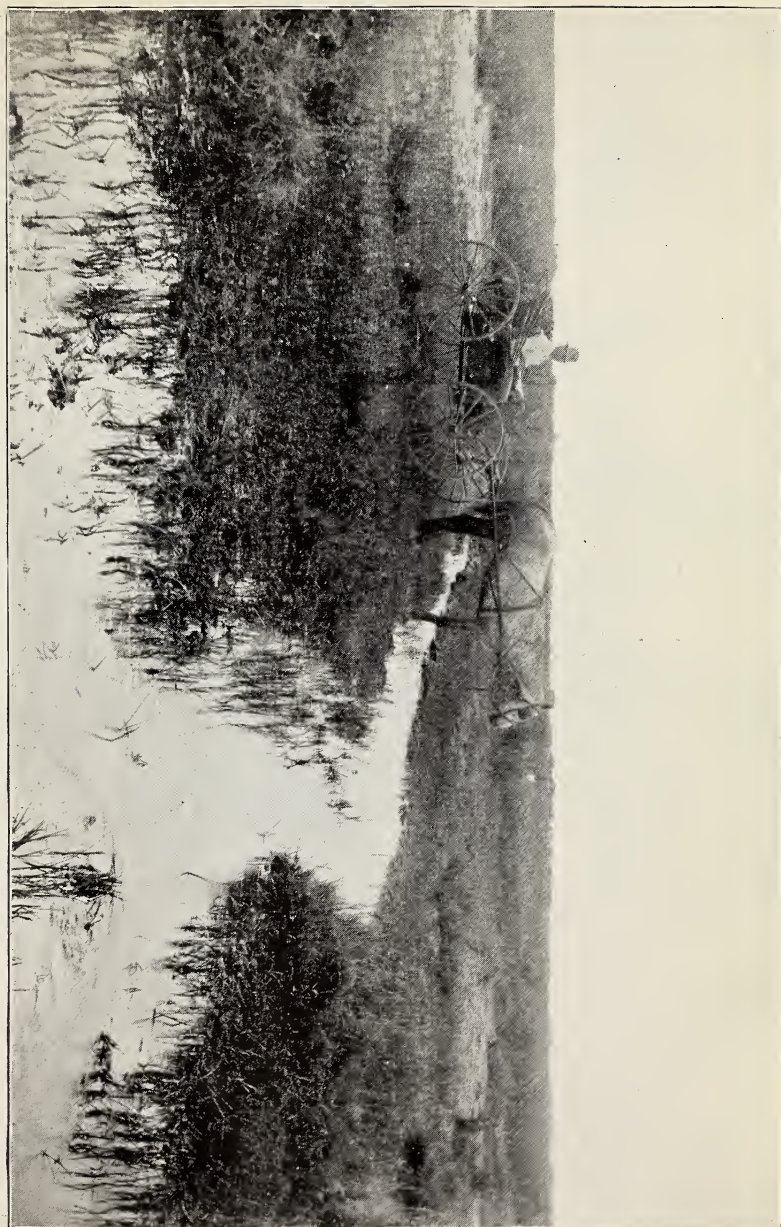
SEEPAGE STREAM FROM THE GYPSUM AREA, FLOWING ABOUT 2 CUBIC FEET PER SECOND.

The loss from the canals flowing through the gypsum area is often enormous.

U. S. DEPT. OF AGRICULTURE
DIVISION OF SOILS
MILTON WHITNEY, CHIEF
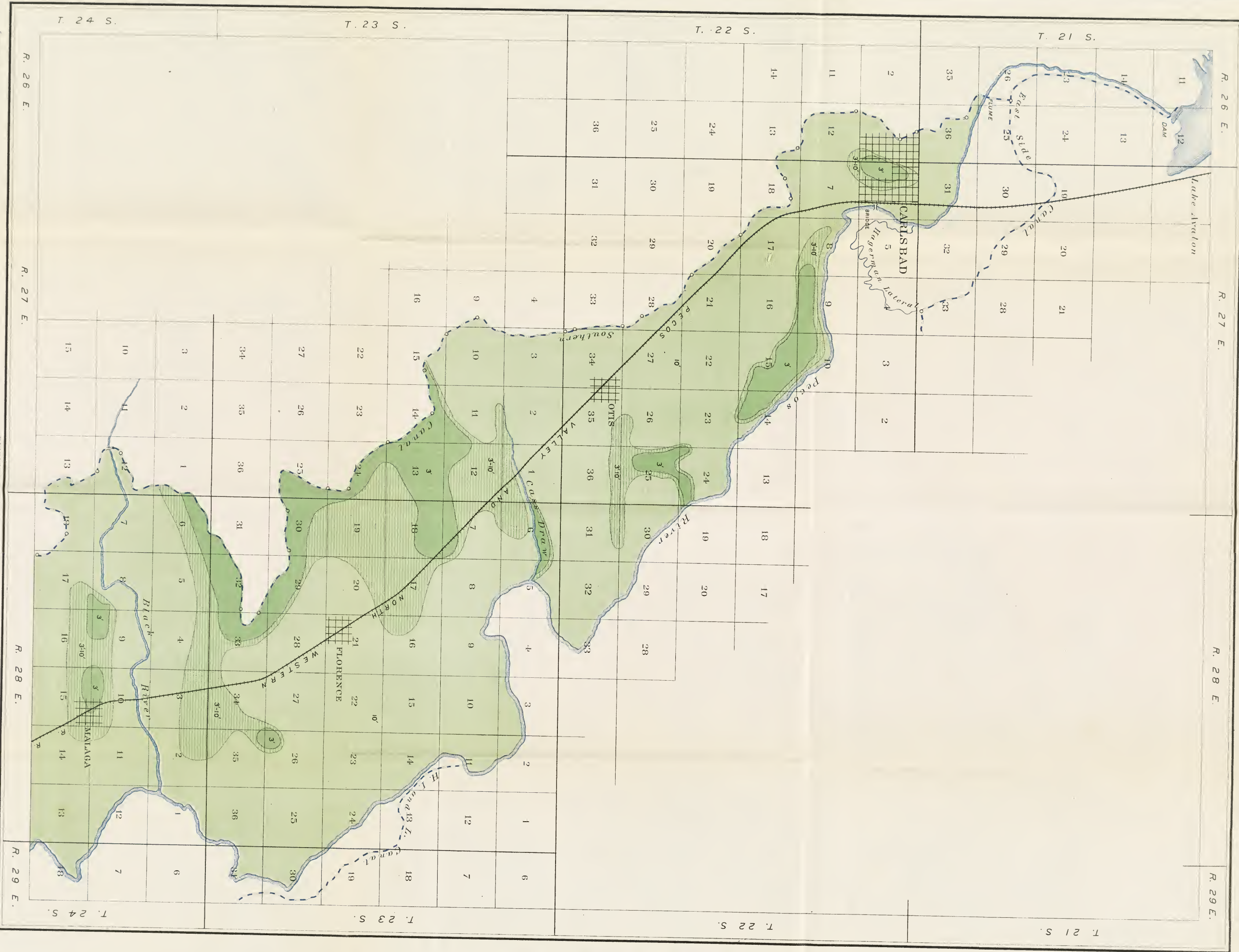
UNDERGROUND WATER MAP

NEW MEXICO
CARLSBAD SHEET

Surveyed by
Thos. H. Means and
Frank D. Gardner
Conditions April–May 1899

Scale 1 in.=1 mile

Edition of 1899

H Doc 399, 56 1

T. 24 S.
T. 23 S.
T. 22 S.
T. 21 S.

R. 26 E.
R. 27 E.
R. 28 E.
R. 29 E.

CARLSBAD

Lake Avalon

DAM

East Side Canal

Hagerman Lateral

Southern

Pecos River

Otis

FLORENCE

MALAGA

Black River

North Western

LEGEND

3'
Water less
than 3 ft. deep

3'-10'
Water 3 ft.
to 10 ft. deep

10'
Water over
10 ft. deep

conglomerate will illustrate this point. In running through the conglomerate directly west of Carlsbad the canal loses 4 cubic feet of water per second in a distance of 1 mile. While this loss is not great when compared with some Colorado canals, as reported by Carpenter, yet the effect of this alkaline water has been seriously felt in the flat to the west of the town, immediately along the foot of the gravel hill. The underground-water map shows an area in which water approaches to within 3 feet of the surface. The greater part of this water is the seepage from the canal, while part is due to the laterals in the town. The water has accumulated to such a degree and has become concentrated to such an extent by evaporation that the park trees and cottonwoods have suffered and many of them have died. A deep drain around the town would largely prevent this damage. Along the foot of the gravel bluffs, in secs. 8, 9, 10, 14, and 15, T. 22, R. 27 E., is another area in which water has seeped out from the gravel bluff, swamping the land. This water flows under the higher lands immediately south, and no doubt has its origin in the canal. Some of the seepage water comes from the irrigation on this upland, but this source seems inconsiderable when compared with the loss from the canal.

A third area of wet land on sec. 25, T. 22 S., R. 27 E. can also be attributed to seepage from the conglomerate. On the edge of this flat water originally stood 40 feet below the surface; while at present, during part of the irrigation season, it is unsafe to attempt to drive a horse along the roads through the flat.

The other areas, shown with water near the surface, are either in the area of gypsum soil or are immediately adjacent to the gypsum. The loss in canals and laterals in the gypsum is great. The measurements in the following table illustrate such loss:

Measurements of loss in canals and laterals by seepage in gypsum.

Lateral from gate 32 loses 1.64 cubic feet per second in 1¼ miles.
Lateral along south side sec. 12 loses 1.71 cubic feet per second in 1 mile.
Lateral from head gate 18 loses 0.89 cubic feet per second in ½ mile.
Main canal between gates 26 and 27 loses 2.62 cubic feet per second in 1½ miles.

All around the canal for a short distance below it the water stands near the surface, coming by direct seepage from the main canal. Along sections 31, 32, and 33 the canal loses 2.6 cubic feet of water in 1½ miles. This water has seeped out, forming ponds below the canal. A number of photographs illustrating the condition of the country and showing the ponds formed from seepage were secured.

One of the photographs shows a stream flowing approximately 2 cubic feet per second, which seeps from the canal. Attempts have been made to stop the seepage from this piece of canal, but so far without success. The canal company contemplates abandoning this piece of canal and running the water directly into Black River, from which it will be taken by a canal to supply the lands south of Black River.

ALKALI IN SOILS.

The alkali map accompanying this report shows three conditions of the soil: (*a*) Soil with less than 0.25 per cent of salt; (*b*) soil with from 0.25 to 0.50 per cent of salt; and (*c*) soil with more than 0.50 per cent of salt. The first represents land which is good; the second, land which contains sufficient alkali to damage crops, but not enough to prevent plant growth; and the third, land which already contains too much salt for crops. The alkali salts are entirely of the white kind—that is, containing no sodium carbonate. The following analyses, by Dr. Frank K. Cameron, were made on samples of crust collected by the members of the Division:

Number.	Locality.	$CaSO_4$.	$MgSO_4$.	Na_2SO_4.	$CaCl_2$.	$MgCl_2$.	NaCl.
4045	Six-mile dam	20.56	13.56	31			36.51
4046	Carlsbad, Pecos bank	3.62	39.92	35.73			20.33
4047	Carlsbad, Pecos bank	3.20	37.19	34.35			26.12
4048	West side Pecos, one-half mile south of Six-mile dam	11.29	25.76	5.67			56.61
4052	Carlsbad, one-half mile above	5.01	53.13	26.02			9.14
4054	Pecos bank, sec. 10, T. 22 S	11.68	54.94	4.60			28.75
4055	Southwest corner orchard, sec. 10, T. 22 S	12.28	21.48	27.47			35.01
4056	Orchard, sec. 14, T. 22 S	7.06	24.52	32.47			38.14
	Alkali flat, sec. 14, T. 22 S	16.53	48.31			7.16	28.20
4053	Pecos bank, 100 yards above	23.45	29.14	28.26			19.14
4057	Mouth of Cass draw	6.33	18.50	33.06			42.11
4058	Sec. 14, T. 22 S	13.39			40.58	18.20	27.83
4061	Sec. 12, T. 23 S	46.44	7.52	26.46			19.57
4063	Delaware River bank	27.42	20.75	26.95			24.87

The soils were shown to contain originally only small quantities of alkali salts in their natural state, but at present there are areas containing great quantities of such salts. The presence of this alkali may, in nearly all cases, be attributed mainly to the salt which is contained in the irrigation water. The chemical composition compares nearly with the chemical composition of the salts contained in the waters. A comparison of the two maps, alkali map and underground water map, shows the relation between the seepage water and accumulations of alkali salts. In the area of gypsum soil the water is frequently below 6 feet, yet the capillarity is sufficient to bring the salt-laden water to the surface for evaporation.

PROBLEMS OF THE AREA.

This area of land, on which immense amounts of work and money have been spent in reclamation, presents a number of problems for serious consideration. There are two important problems which are in a measure peculiar to the Carlsbad district. These are the methods of irrigating with an alkali water and the cultivation of gypsum land. The character of the water is the most serious difficulty in the way of profitable irrigation. To develop a new supply of water would be an engineering problem difficult of solution. The use of the present supply is attended with possible loss of crops, especially where the most favorable conditions do not exist. The greater part of the area of Pecos sandy loam has good drainage at present, and the difficulties

PLATE VIII.
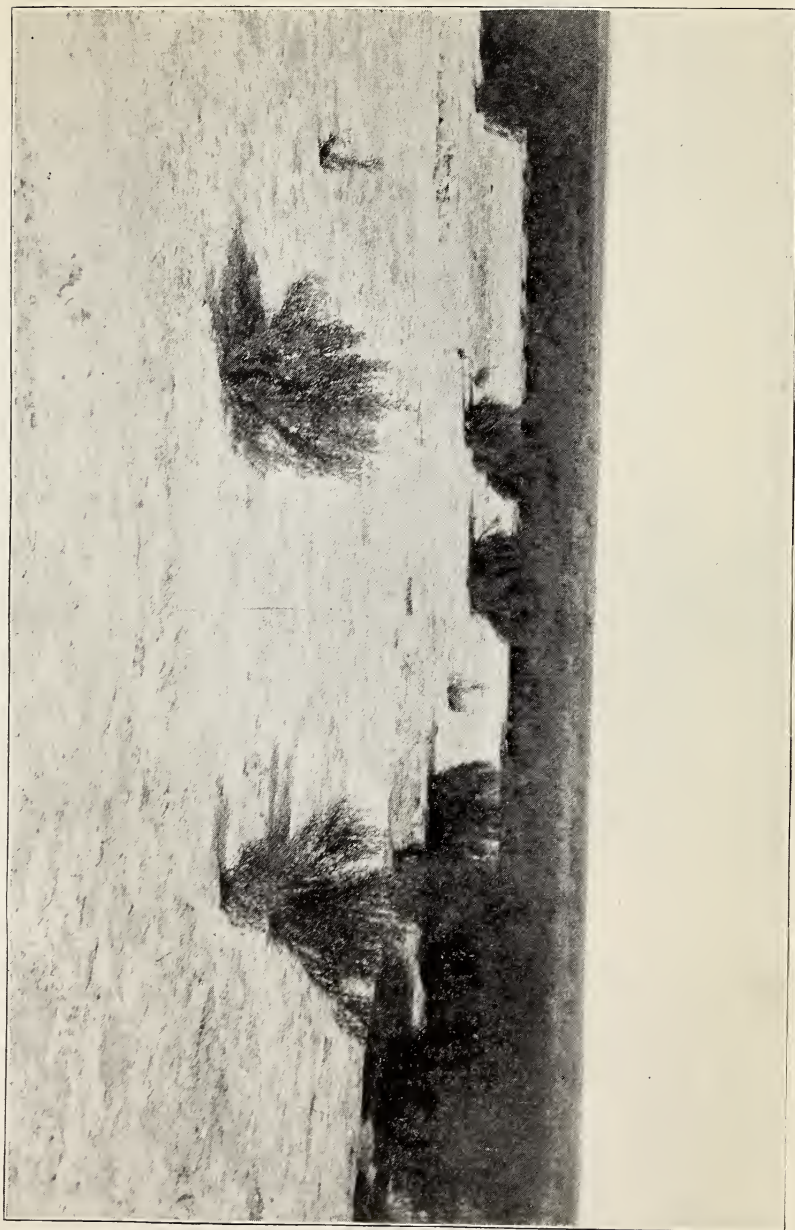
ALKALI FLAT CAUSED BY SEEPAGE AND SUBIRRIGATION OF THE GYPSUM LAND.

Where the drainage is insufficient to carry the seepage water off these alkali flats are formed.

PLATE IX.
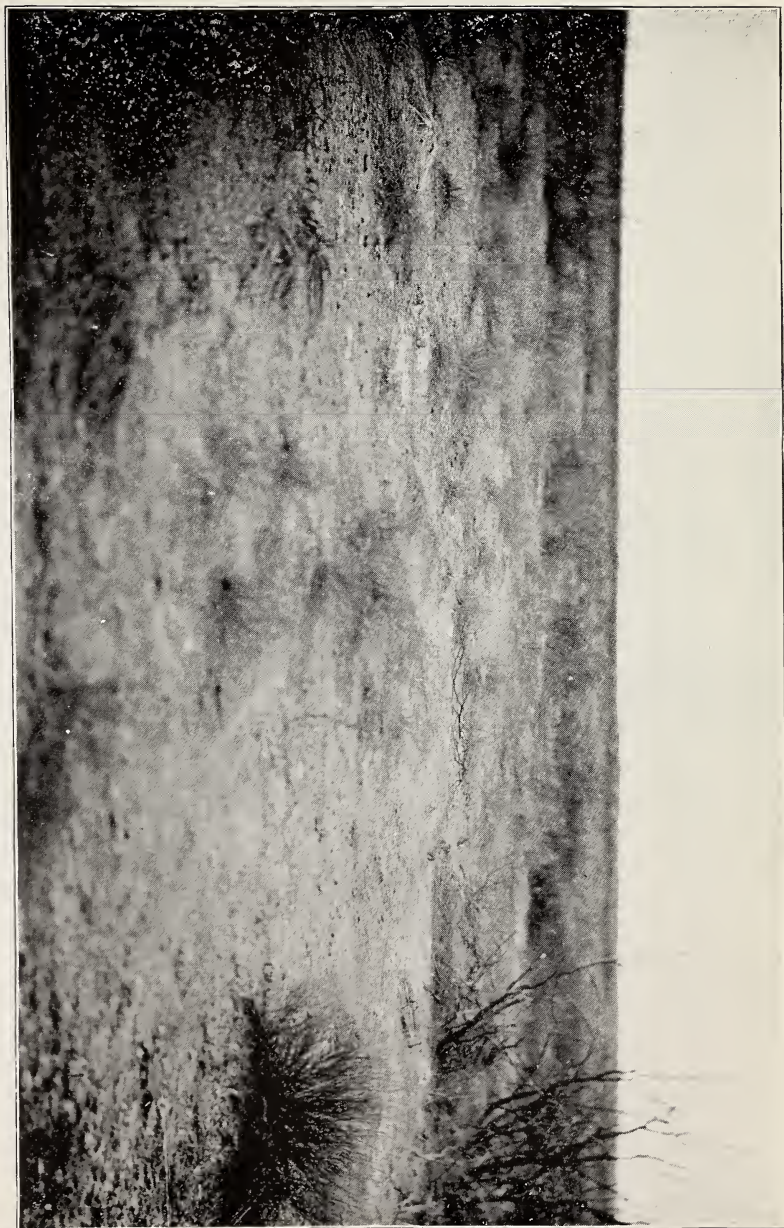
ALKALI FLAT FORMED BY SEEPAGE FROM CONGLOMERATE.

Most of the drainage in the Carlsbad area is due to the seepage through the gypsum and conglomerate.

encountered in these soils are at a minimum. Wherever the level of standing water is below 10 feet, there is no present need of drainage; but where (during its yearly fluctuations) the level of standing water approaches the surface of the ground as close as 3 feet, drainage must be installed. Moreover, the accumulation of alkali from the summer's irrigation should be removed by flooding and drainage during the late summer and autumn when the irrigation water is at its best.

BARSTOW AREA, TEXAS.

A brief examination was made of the conditions at Barstow, Texas. Here the water is taken out of the Pecos River by a diverting dam without storage. The water at this point contains more salt than the Pecos water at Carlsbad. Receiving, as it does, the drainage and seepage waters from the Carlsbad irrigated lands and being augmented by alkali springs along its banks, the water at Red Bluff, below the lower limit of irrigation in the Carlsbad district, carried in May, 1899, 320 parts of soluble matter per 100,000. The waters of the Pecos at the Barstow intake carried in June 390 parts of soluble matter per 100,000, and opposite Pecos City, below all irrigation, it carried 525 parts per 100,000.

The application of water of this character to the soil, if long continued, is sure to result in an accumulation of salts beyond the endurance of agricultural plants, unless good natural drainage is present or provision made for the escape of the salts by means of underground drains.

The soils are derived from the ancient lake basin sediments and are heavier in texture than the soils of the upper Pecos Valley. They originally contained greater quantities of alkali salts and, in fact, there are evidences of the accumulation of salts in beds at depths below the surface. The soil of much of this area is underlaid by gypsum. This in its turn introduces new complications which render irrigation farming in this district extremely difficult.

The most favorable conditions only can be relied upon to give profitable results in the irrigation of this district. The land has been under cultivation for about five years and, owing to excessive leakage from canals, seepage waters have accumulated to such an extent that much of the land has already been abandoned. All of the lands on the Pecos City side have been abandoned, and at present irrigation is confined to the Barstow or eastern side of the river.

The most promising field for such a district would be the cultivation of saltbushes and other plants resistant of alkali. Water from the Pecos, when the water is in its best condition, should be flooded over the land to wash away accumulated salts near the surface. This salt would have to be removed by good underdrainage, if intensive farming is contemplated.

A district lower down on the Pecos is reported to be entirely abandoned from the excess of alkali which the water and soil contained.

SUMMARY.

The foregoing pages have shown that the condition of the water in the Pecos River becomes more saline as one descends the river. This fact is well brought out in the sketch map of the Pecos Valley, fig. 5. On this map the parts of salt per 100,000 parts of water are shown by figures. The seriousness of the alkali problem varies in direct ratio to the salt content of the water. At Roswell the alkali is within the soil; the irrigation water is good. By washing the alkali from the soil with the pure water the alkali may be removed and the land thoroughly reclaimed. If once the alkali is removed by the soils being drained, there need be no further fear of damage from alkali. The water of the Berendos contains alkali in sufficient quantity to be harmful to lands, unless well drained. The use of this water has been almost entirely restricted to lands lying close to the deep-cut river channels, where natural drainage is good; therefore the damage from this water has been slight. The water of the Northern Canal contains 0.2 per cent of alkali, and care should be exercised in using it. The soils at Hagerman contain at present alkali, most of which has been derived from the evaporation of the Northern Canal water.

The water of the Carlsbad system contains on an average 0.31 per cent of alkali salts. The soils originally contained very little alkali, the greater part of that now present being due in all probability to the concentration of the irrigation water. The salt already accumulated must be removed by drainage, and all further accumulation must be prevented by washing out with fresh water during the winter or when the water is plentiful and fresh.

The soils of the Pecos Valley are deficient in organic matter and nitrogenous plant food. The growth and plowing under of leguminous crops is recommended, together with fertilizing with stable manure when such is attainable. In the southern part of the valley, where sugar beets form a money crop for the farmer, chemical fertilizers would be of value. Economy in the use of water and the prevention of leakage from canals or laterals will overcome much of the seepage, which at present is the principal cause of the alkali.

The authors wish to acknowledge their indebtedness to Mr. W. Hamilton, manager of the Roswell Land and Water Company, for base maps and for material assistance in the prosecution of the investigation in the Roswell district; also to Mr. Charles A. Bremond, Mr. Luigi Martini, and others for help and interest shown in the work.

At Carlsbad credit is due to Messrs. Tansil, F. A. Tracy, and W. M. Reed, officers of the Southern Canal system, for maps and assistance, and to Prof. E. M. Skeats for valuable data, including chemical analyses relating to the district; also to A. E. Goetz and others.

During the short time spent at Barstow, Tex., Mr. G. E. Briggs, manager of the Pioneer Canal Company, assisted personally in the reconnoissance of that district.

A SOIL SURVEY IN SALT LAKE VALLEY, UTAH.

By FRANK D. GARDNER and JOHN STEWART.

PHYSIOGRAPHY.

Beginning in July, 1899, four months were spent in a thorough and detailed study of that portion of the Salt Lake Valley lying west of the Jordan River, the object being to map the soils with reference to their character and to the extent of, and damage from, "alkali" and seepage waters. The soils were classified according to their texture, and the waters examined with reference to their quality for irrigation purposes. The soils were further studied with reference to their "alkali" content and its effect in varying amounts upon the crops and vegetation. The methods of irrigation were looked into with regard to their success or failure and the ultimate outcome in relation to the condition of the soils, especially with reference to the accumulation of alkali and seepage waters.

Nearly 700 borings were made in this district, usually to a depth of 6 feet and occasionally to 9, 12, or 15 feet. In two-thirds of these borings the per cent of salt at saturation in each foot section was determined by the electrical method, and in a considerable number of the borings the sodium carbonate (true black alkali) was determined volumetrically. In areas where hardpan forms an important feature, it was mapped and its depth and thickness ascertained. A study was made of its influence toward the action of roots and water together with the probable mode of formation.

Full notes were made on the character of the natural vegetation and the kinds and condition of the crops. Wells, both surface and artesian, were examined with reference to their water, the depth to standing water, and the nature of the strata through which they were dug. Drainage and seepage waters were tested with regard to the salts they were carrying from the soil.

Only such of the data collected as is essential for a clear understanding of the conditions is herein given, the results being embodied in the following text and accompanying maps.

Salt Lake Valley comprises about one-half of Salt Lake County, the remainder being occupied by the Wasatch Mountains to the east and

the Oquirrh Mountains to the west. The mountains close in on the south in what is known as the Jordan Narrows, thus practically surrounding the valley on three sides and leaving an opening on the north where it borders on the Great Salt Lake. It is one of many similar valleys which, lying between mountain ranges more or less parallel, go to make up the lower and more level parts of the Great Interior Basin, a broad area of varied surface naturally divided into a number of drainage districts.

The general form of the Great Interior Basin is triangular, with the acute angle to the south where it extends into old Mexico. At its greatest extremes it is 880 miles from north to south and 570 miles from east to west, including an area of 210,000 square miles. It comprises nearly the whole of Nevada, the western half of Utah, small portions of Idaho and Montana, and large areas in Oregon and in eastern and southern California.[1]

The region is characterized by many short and usually parallel mountain ranges, extending generally from north to south, between which are smooth valleys whose alluvial slopes or floors are built up of the débris brought down from the mountains. The character of the climate is plainly seen in the hydrography and vegetation. Perennial lakes occur only in association with the larger mountain masses, while the vegetation of the valley is usually sparse. The annual rainfall varies from 2 inches in the south to about 20 inches in the mountains in the north, while the annual evaporation from a free water surface varies from 60 inches in the north to 150 inches in the south. The larger mountains have timber in their recesses, but only conifers attain such size and abundance as to be of economic importance. The climate of the whole area may be classed as arid.

The largest subdivision of the Great Basin is the Bonneville Basin (fig. 6), containing 54,000 square miles, or a little more than one-fourth of the former. Slightly more than two-fifths of the Bonneville Basin was once occupied by the ancient Lake Bonneville, whose area was 19,750 square miles. This ancient lake apparently reached its greatest extent during the epoch of maximum glaciation, as is shown by the presence of a number of glacial morains which descend on the sides of the Wasatch Mountains to the well-marked shore line of the lake when at its highest stage. This shore line, known as the Bonneville shore line, forms a striking feature of the mountain side, both to the east and west, and is plainly visible from all points of the valley. (See Plate X.) The great upheavals which made the mountains and valleys of this region evidently occurred prior to the age of the lake, although there have been

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[1] The following brief description of the characteristics and history of the Great Interior Basin and of Lake Bonneville is essential to an understanding of the present conditions. Some of the facts and figures relating to the basin and to the time and extent of the ancient lake have been taken from G. K. Gilbert's report on Lake Bonneville, published as a monograph by the United States Geological Survey in 1890.

LEGEND

SOIL PROFILE
(6 feet deep)

- S — Sand
- C — Clay
- Ss — Sandy loam
- Sc — Gravel
- Gr — Gravel loam

- S — Salt Lake Sand
- S — Jordan sand
- C — Jordan sandy loam
- Sc — Ssc
- S — Jordan loam
- C — Sc
- S — Jordan clay
- C — Sc
- Gr — Bingham gravel loam
- Gsc — Ssc
- S — Bingham Stony loam
- Ss
- Gr — Jordan meadows
- C — S — Sc

LEGEND (lower)

- Js — Jordan sand
- SLs — Salt Lake sand
- Jsl — Jordan sandy loam
- Jl — Jordan loam
- Jc — Jordan clay
- Bgl — Bingham gravel loam
- Bsl — Bingham stony loam
- Jm — Jordan meadows

GREAT SALT LAKE

SALT LAKE CITY

HERRIMAN

Utah and Salt Lake Canal
South Jordan Canal
North Jordan Canal
Brigham and North Point Canal
JORDAN RIVER
RIO GRANDE R. W. R. R.
OREGON SHORT LINE R. R.
SALT LAKE & LOS ANGELES R. R.

Saltair Beach
Pavilion
Decker L.
Silver Lake
Mud L.
Williams Lake
Utah Strand

minor changes in the elevation since then, as shown by faults at the western bases of the Wasatch, Oquirrh, and Aqui mountains and by the variations in the altitude of different parts of the Bonneville shore line. The altitude of this shore line has been ascertained in a number
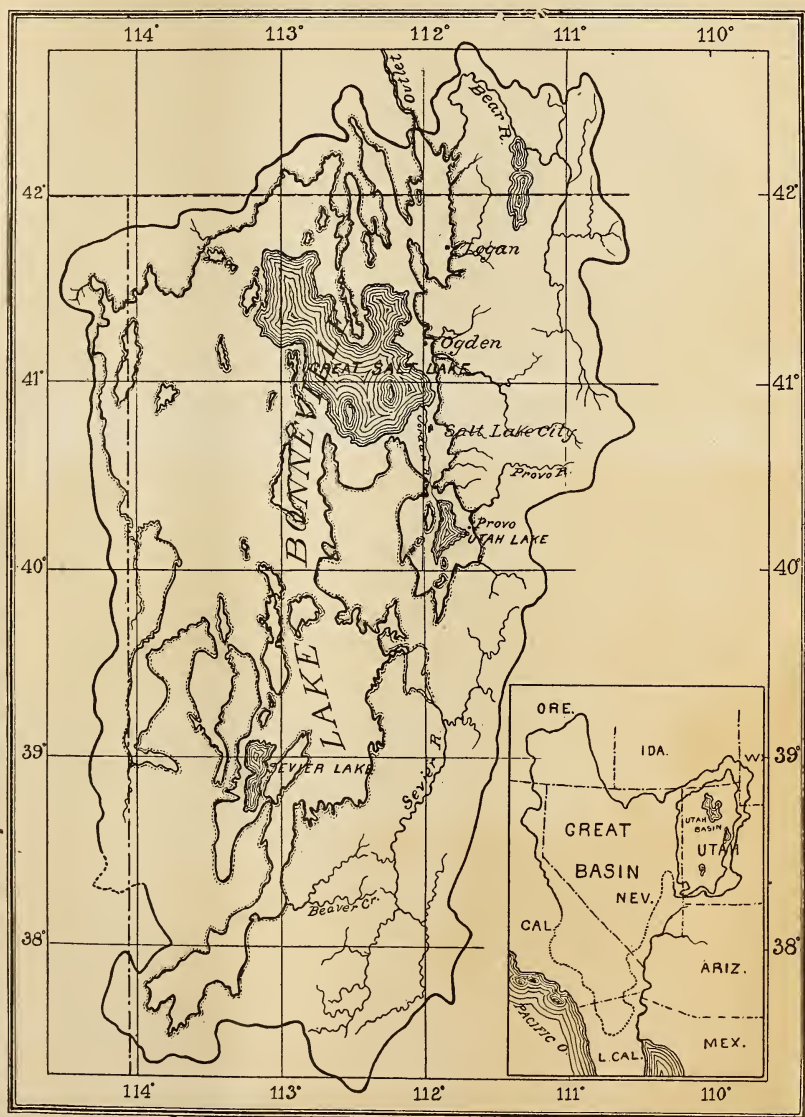
FIG. 6.—Sketch map of Bonneville Basin, showing ancient lake and present lakes.

of places, and, except in a few measurements at the extreme south, it varies from 900 to 1,070 feet above the present level of Great Salt Lake, with a mean elevation of about 1,000 feet. All evidences point to the fact that the surface of Lake Bonneville was at that time 1,000 feet

higher than the present surface of Great Salt Lake and that its areal extent exceeded the present lake by 13.3 times. At its highest stage the lake overflowed the rim of the basin, the water escaping into Snake River. A deep channel was eroded, forming what is now known as Red Rock Pass. The level of the lake was thus lowered 375 feet, at which point erosion ceased and no further escape of water occurred in this manner. Here the water level was maintained for a considerable period of time, as is shown by the formation of a well-marked beach line which is known as the Provo shore line. After this stage the lake water fell to its present level by evaporation, occasional interruptions being now noticeable by the number of intermediate shore lines more or less distinct. There is strong evidence of very great climatic change from epochs of great precipitation of snow and rain to periods when high temperature and excessive evaporation occurred. It is not at all improbable that the Great Salt Lake may have been dry at some period, although this question has never been settled.

The modern Great Salt Lake is but a remnant of its ancient predecessor, which at the time of its overflow may be considered as a freshwater lake. Since the Provo stage, however, the water escaped only by evaporation through a long period of time during which the evaporation exceeded the precipitation, causing as a result a body of water containing in solution 22 per cent of salt. At the Provo stage the water surface of the ancient lake was 625 feet above the present level of the Great Salt Lake as determined by the altitude of the Provo shore line in a number of places. (See Plate X.) The mean depth of Great Salt Lake is now about 13 feet; therefore, the water over its present area at the Provo stage was forty-nine times its present depth. A comparison of its area at the two periods shows that at the Provo stage it was 7.4 times its present area. Assuming that the mean depth of the whole body of water at this early period was one half the mean depth of water at that time over the present lake, the volume of water at the former time is found to be one hundred and eighty-one times the present volume of Great Salt Lake. If it were further assumed that the lake at the Provo stage was fresh and contained, as the Utah Lake now does, about 80 parts of soluble matter in 100,000 parts of water, we would have, by evaporation to the present volume of Great Salt Lake, a solution containing 14.5 per cent of salt, providing none of the salt was precipitated during the process of evaporation. As a matter of fact the lake now carries about 22 per cent of salt, which leaves about 7½ per cent unaccounted for. We find, however, that the inflowing streams carry sufficient water to equal the volume of the lake water every 2½ years; and if it is assumed that they carry a percentage of salt equal to that carried by Utah Lake, it would require only two hundred and fifty years for them to carry the remaining 7½ per cent and bring the saltness of the lake to its present stage. No doubt considerable quantities of the less soluble salts—as, for example, carbonate of lime and sulphates of
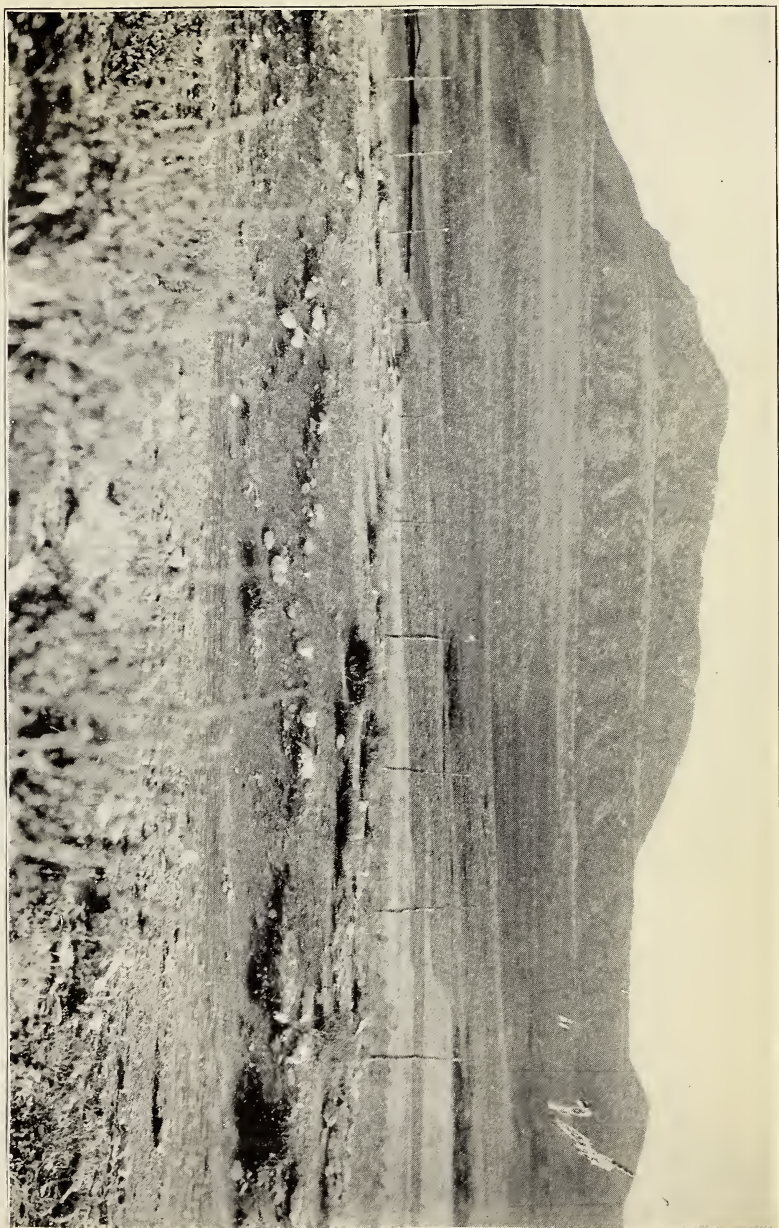
LAKE BONNEVILLE MARKS ON MOUNTAIN, 3 OR 4 MILES EAST OF GARFIELD BEACH.

The upper bench line is the Bonneville shore line, and the lower well-defined one is the Provo shore line. The lake overflowed 375 feet between these levels, and has since evaporated 625 feet, down to its present level.

ALKALI MAP
UTAH
SALT LAKE SHEET

SALT LAKE CITY

HERRIMAN

JORDAN RIVER

Utah and Salt Lake Canal

South Jordan Canal

North Jordan Canal

Brighton and North Point Canal

South Point (Intercolonial) Canal

SALT LAKE & LOS ANGELES R.R.

OREGON SHORT LINE R.R.

RIO GRANDE W.R.R.

Silver Lake
Decker L.
Porter L.
Becker L.
Water Lake
Williams Lake
Calms Slough

Utah Beach
Pavilion
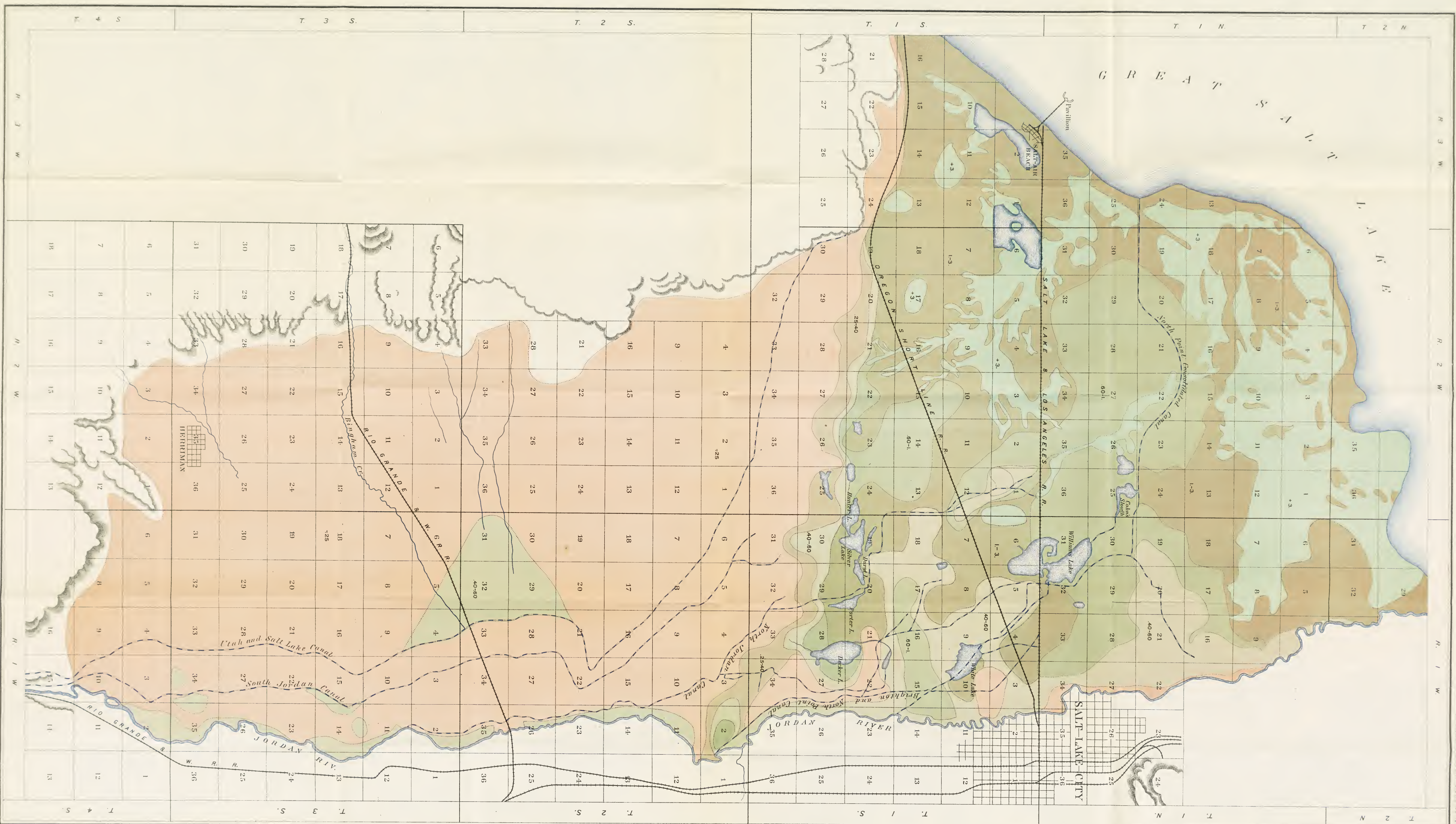
LEGEND

25%	Less than 25 per cent
25-40	From 25 per cent to 40 per cent
40-60	From 40 per cent to 60 per cent
60-1	From 60 per cent to 1 per cent
1-3	From 1 per cent to 3 per cent
+3	Over 3 per cent

lime and soda—were deposited, but the period of time since the Provo stage has undoubtedly been much longer than two hundred and fifty years. It seems, therefore, quite simple to account for the present high salt content of the Great Salt Lake. At a time when the lake was just high enough to cover the lower levels of the Salt Lake Valley, the water must have been sufficiently salty to have left the soil in a very salty condition upon the subsidence of the water. As a matter of fact, large amounts of salt are found in the lower levels, especially in the lower depths of the soil.

Within the memory of the present inhabitants the level of this lake has varied fully 1½ feet. In 1850 it was very low, but for several years thereafter it rose slowly. It then began to fall again, reaching a very low stage from 1861 to 1864. From 1864 to 1868 there was a period of excessive rainfall, during which time the lake rose rapidly, reaching such a height in 1868 that fully 50 square miles of what was mapped
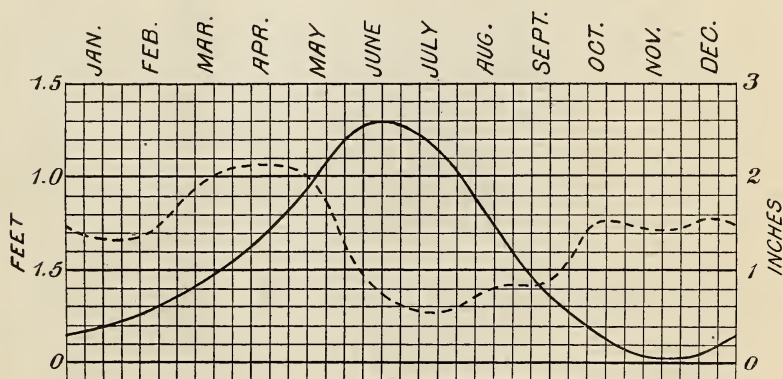
Fig. 7.—Diagram showing mean monthly fluctuations in water level of Great Salt Lake and the rainfall during same period. (The solid line represents level of lake; the broken line the rainfall.)

this season as dry land was submerged by its waters. Since that time there have been three distinct periods of rise and fall, but the general trend has been downward, until at the present time the level is about where it was in 1850. Besides this, there is an annual fluctuation, during which the lake reaches its maximum about June 1 and its minimum about December 1. This annual variation, amounting to from 1 to 2 feet, is the result of a low rainfall from June to September, inclusive, accompanied by high temperature and low relative humidity, conditions favoring rapid evaporation and of a greater rainfall and less evaporation during the remainder of the year. This is shown in figure 7.

The accompanying diagram (fig. 7) shows graphically the mean monthly rainfall in inches as compared with the monthly change in the level of the lake in feet. The maximum rise of the lake occurs about two months after the close of the rainy period, and it is about the same length of time after the rain again begins before the lake commences

to rise, which shows that the maximum effect of precipitation on the lake occurs about two months after the precipitation has taken place. Figure 8 shows the semiannual variation in the lake level for the past fifty years, with the accompanying annual rainfall. There is a general agreement between precipitation and the lake variation.

The surface of Great Salt Lake is 4,170 feet above the sea level, while an additional 50-foot contour line would include the lower and more level portions of the valley, amounting to one-half of it. Above this the land inclines toward the foothills at the rate of from 50 to 100 feet per mile. To the east the Wasatch Mountains rise abruptly, attaining a maximum height of 7,000 feet above the general level of the valley. Their snow-clad summits and numerous springs are the source of a number of perennial streams that flow across the eastern part of the valley and enter the Jordan River. These streams furnish an
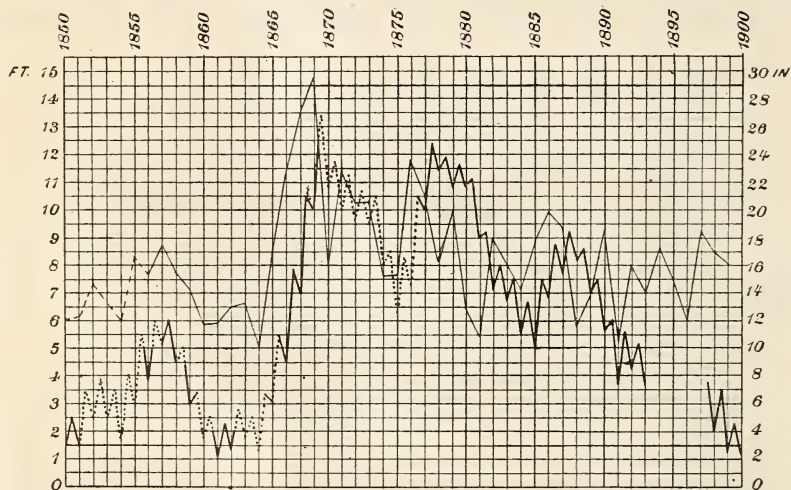
FIG. 8.—Diagram showing mean annual fluctuations in water level in Great Salt Lake and the rainfall during the same period. (The heavy line represents the level of the lake in reference to an established bench mark; the light line represents the rainfall in inches.)

abundant and good water supply for irrigating the eastern portion of the valley. To the west the Oquirrh Mountains rise less abruptly, reaching an elevation of from 4,000 to 5,000 feet above the valley. The watershed is not so extensive as to the east, and there is less snow, so that the few streams flowing from the canyons are lost, by evaporation or seepage, before they reach the Jordan River. The Jordan River is the main channel through which the waters of Utah Lake and its inflowing streams reach Salt Lake. It is on the Jordan River that the western portion of the valley is dependent for irrigation water.

The mountains consist chiefly of granite, limestone, sandstone, quartz, porphyry, and feldspar, and it is from these rocks that the soil of the valley is formed. The mountains abound in ores rich in silver, lead, and copper. Many mines are in operation and furnish material for several large smelters located in the valley.

The lake is also a source of commercial enterprise, and according to the statistics of 1890 the value of the annual output of the salt harvested from the evaporating ponds amounted to $250,000.

CLIMATE.

The climate of Salt Lake Valley is characterized by low annual precipitation, low relative humidity, moderate wind movement, moderate temperature, and abundant sunshine. It may be classed as arid. According to the United States Weather Bureau records for the past 25 years, the mean annual precipitation at Salt Lake City is 16.2 inches, with a minimum of 10.3 inches in 1890 and a maximum of 23.6 inches in 1875. Previous records, shown in the chart on page 82, show a range in annual precipitation of from 10 to 29 inches. Of the mean annual rainfall a total of only 2.9 inches falls during the months of June, July, August, and September. These four months of mean minimum precipitation are accompanied by mean maximum temperature and low relative humidity—conditions favoring excessive evaporation.

Since this is the period in which crops make most of their vegetative growth, it will be seen how important and necessary is irrigation water for farming. In fact very little farming is carried on except under irrigation. Statistics for 1894 show that 92.5 per cent of the farms in Salt Lake County are irrigated. Wheat is the only crop that is grown without irrigating and it makes most of its vegetative growth prior to June. The average yield of wheat under dry farming is slightly more than one-third of the average yield under irrigation.

The accompanying table shows the monthly and yearly precipitation at Salt Lake City for the past 25 years as obtained from the United States Weather Bureau office at that place.

Monthly and annual precipitation, Salt Lake City, Utah, from 1874 to 1899.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1874			a1.31	0.90	2.84	0.74	2.42	1.63	0.20	1.74	2.16	0.73	14.67
1875	3.05	2.81	1.50	2.91	.90	1.01	.25	1.22	1.36	5.81	2.03	.79	23.64
1876	1.23	1.52	4	2.09	4.30	.09	.83	.92	.42	3.27	.81	1.80	21.28
1877	.87	.38	2.93	2.14	3.49	.80	.02	.28	.90	2.41	1.02	1.11	16.35
1878	1.07	3.49	2.54	2.63	2.50	.35	1.08	.81	3.15	1.39	.63	.11	19.75
1879	1.87	.71	.67	3.26	.10	1.34	.07	.06	.01	1.62	.32	3.08	13.11
1880	.29	1.02	.43	2.37	1.85	.01	.20	.74	.56	.40	1.17	1.90	10.94
1881	1.24	2.44	.88	2.37	2.55	.28	.21	1.66	.43	2.19	1.44	1.24	16.93
1882	1.50	.42	1.12	3.81	.26	2.24	.30	1.61	.37	2.89	.54	.92	15.98
1883	1.47	.72	1.75	2.92	.98	.33	.10	.62	.13	2.24	1.78	1.20	14.24
1884	.71	2.23	3.69	2.89	1.78	.33	.27	.73	1.91	.36	.50	2.12	17.52
1885	1.48	1.56	.64	b3.47	2.49	2.67	.58	.90	1.29	.59	3.10	.92	19.69
1886	1.91	1.36	2.60	4.43	.06	1.02	T.	.59	1.88	1.98	1.79	1.27	18.89
1887	2.36	1.41	.35	1.87	.73	.37	1.23	.69	.55	.30	.25	1.55	11.66
1888	1.52	1.22	2.18	.99	.34	.98	.24	.63	.51	.80	2	2.21	13.62
1889	.73	.81	1.64	1.52	2.97	.01	.08	.92	.52	3.85	1.04	4.37	18.46
1890	3.07	2.05	1.12	.94	.16	.32	.02	.79	T.	1.44	T.	.42	10.33
1891	.74	.76	4.66	1.49	.72	1.08	.47	.46	1.19	1.26	.90	2.19	15.92
1892	1.61	.68	2.21	1.90	1.65	1.21	T.	.05	.12	1.58	.72	2.35	14.08
1893	.82	1.64	2.68	2.72	1.68	.04	1.19	.71	1.30	1.02	1.18	2.37	17.35
1894	1.31	.83	1.73	1.67	1.22	1.38	.82	.87	2.87	1.01	.28	1.28	15.27
1895	1.32	.85	.81	.73	2.29	.99	.42	.02	.95	.24	2.44	.89	11.95
1896	1.26	.69	1.99	2.53	3.67	.25	1.35	1.47	.52	.70	3.15	.84	18.42
1897	1.16	3.81	2.20	2	.98	.52	.69	.33	.48	1.91	1.19	1.47	16.74
1898	.58	.38	1.71	1.30	4.19	1.45	.18	1.35	.15	1.57	1.95	1.28	16.09
1899	.84	2.98	2.93	.81	2.59	.96	.42	1.06	T.				12.59
Sums	34.01	34.75	51.58	55.25	49.30	20.66	14.20	20.15	21.63	38.12	36.17	39.65	402.88
Averages	1.36	1.39	1.98	2.12	1.90	.79	.55	.78	.83	1.52	1.45	1.59	16.18

a 12 days.   b 28 days.

The annual precipitation in the mountains is greater than in the valleys, and it is estimated that it includes 6 feet of snow, which lingers on the mountains the greater part of the summer. This is important in relation to irrigation, because it makes the water supply plentiful throughout the season.

The annual evaporation from a free water surface in Salt Lake Valley is estimated at 8 feet. Data from one of the salt companies show the evaporation from their ponds to be about 37 inches from June to September, inclusive. It should be borne in mind, however, that this is from a saturated salt solution and that the presence of much salt lowers the vapor tension, and, consequently, the rate of evaporation. The evaporation from a fresh-water service would no doubt have been much greater.

The mean annual temperature is 51.2° F., with a mean maximum of 75.6° in July and a minimum of 27.9° in January. The mean temperature for from June to September, inclusive, is 70.5° F.

The following table gives the mean monthly and mean yearly temperature for the past twenty-five years.

Mean monthly and mean annual temperature, Salt Lake City, Utah, from 1874 to 1899.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1874	....	....	....	....	....	67.1	77.8	74.6	62	56.4	43.2	33.9	....
1875	29.5	34.2	35	48.9	59	67.8	74	75	68.1	58.2	42	36.2	52.4
1876	30.5	36.1	37.2	49.8	56.7	68.6	76.5	71.6	65.8	55.3	41	27	51.2
1877	27.2	34.1	46.9	48.8	56.2	65.4	77.4	75.8	64.4	51.6	40.6	32.1	51.4
1878	30.3	37.8	47.1	49.4	56.4	68.5	76.9	78.4	60.6	49	44	29.8	51.9
1879	28.3	39.6	49.2	52.6	58.2	65.2	76.8	75.4	68.5	52	36	29.4	53
1880	28.2	26.2	34	46.8	54.2	66	74.2	72.8	63.6	52	29.6	34.6	48.6
1881	30.8	38.2	42.2	54.2	60.2	71.2	76	74.4	60.2	50.8	33.8	33.6	51.8
1882	23.5	26.9	36.6	46.7	57.2	67.3	75.4	76.9	64.8	48.4	35.5	35	49.2
1883	24.4	24.1	47	45.6	56.7	70	76.2	76.8	69.7	46.3	39.2	32.5	50.8
1884	28.4	30.7	40.8	48	57.9	69.1	74	72.7	59.4	53	42.2	35.2	51.4
1885	27.6	36.8	45.6	53.5	56.6	64.8	76.1	73.7	65.1	54.9	43.8	33.9	52.3
1886	28.8	40.8	37.7	48.4	62.4	68.9	78.1	76.1	62.8	51.8	31.4	36.1	51.6
1887	33.2	34.1	47.2	49.2	60.8	68.6	74.9	73.4	65.5	51.6	42.8	29.2	52.7
1888	22.9	38.3	40	54.8	58.6	68.4	76.6	74.8	70.6	54	41.6	35.8	53
1889	21.4	29.8	47.7	55.2	58.8	70.3	78.4	77.4	60.6	54.2	39	39.6	52.7
1890	24.8	33.7	39.5	50.4	61.3	64.8	77.8	72.9	65	48.6	41	36.2	51.6
1891	28.8	30.6	38	49.6	60	62	73.3	74.4	65	53.2	44.2	28.6	50.6
1892	25.8	33.6	43.4	47.4	55.4	65.8	76	75.4	69.6	51.8	42.2	27.6	51.2
1893	27.6	28.5	39.3	45.9	55.1	67	74.7	73.3	63	52	39.4	36.3	50.2
1894	29	25.6	41.1	48.1	61.2	63.9	74.6	75.4	61	53.2	45.6	31.4	50.8
1895	29.7	30	40.8	51.2	57.9	63.5	72.6	74.8	63.8	54.3	37.8	26.4	50.2
1896	34	36.8	40.2	46.4	51.4	70	74.2	73.7	64	54.4	37.2	36.2	51.5
1897	28.8	30.9	33.6	49	63.4	66	71.9	75.2	62.2	50.9	43.2	27.4	50.2
1898	20.6	35.6	36.3	54	53.9	67.1	75.9	76.8	65.6	48.2	37.3	25.2	49.7
1899	33.8	29.6	40.6	50.6	52.6	65.1	76.2	69.8	67.1	....	....	....	....
Average	27.9	32.9	41.1	49.8	57.7	67	75.6	74.7	64.5	52.2	39.7	32.4	51.2

The mean annual wind movement is at the rate of 5.4 miles per hour, with a maximum of 6.4 miles in May and a minimum of 4.3 miles in November.

The following table gives the monthly and annual wind movement at Salt Lake City for the past twenty-five years. As a whole, the climate is both pleasant and healthful.

Monthly and annual wind movement in miles at Salt Lake City, Utah, from 1874 to 1899.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1874	......	......	......	4,227	4,116	4,231	3,421	3,924	3,240	2,681	3,076	2,272	a 31,188
1875	3,395	2,701	4,492	4,394	4,672	4,407	3,923	4,406	3,983	3,087	3,262	2,031	44,753
1876	2,915	2,460	4,169	3,689	3,537	3,570	4,252	4,910	4,524	3,418	2,887	1,636	41,967
1877	3,222	2,411	4,219	5,206	6,291	4,531	5,165	4,848	4,783	3,998	3,777	2,978	51,429
1878	2,569	3,568	4,150	5,057	5,229	4,970	5,535	4,083	3,830	4,406	3,148	2,895	49,440
1879	2,898	3,336	5,001	4,739	6,410	5,085	4,503	4,783	4,104	3,694	2,222	3,605	50,380
1880	3,516	3,292	5,003	5,693	5,475	4,534	4,090	3,878	3,601	3,499	2,090	3,801	48,572
1881	3,360	2,072	4,045	3,174	3,773	2,759	4,394	4,199	3,916	4,000	2,205	1,473	40,370
1882	2,100	2,952	3,810	5,009	5,569	4,713	4,321	4,476	3,779	3,895	2,613	2,726	45,963
1883	2,333	2,590	4,136	4,914	3,350	4,168	3,224	3,312	3,793	3,746	3,166	2,984	41,716
1884	3,257	4,075	4,662	4,443	4,613	4,875	4,023	3,492	3,844	3,947	2,422	5,410	49,063
1885	2,410	2,378	2,770	3,006	2,652	3,853	4,366	3,921	3,584	2,823	3,705	2,808	38,276
1886	3,520	2,822	3,736	4,319	4,534	4,146	4,287	3,210	3,734	4,193	2,730	2,239	43,470
1887	3,862	5,350	3,933	4,877	4,926	4,589	3,800	4,524	3,723	3,414	2,863	3,406	49,267
1888	3,776	3,201	4,736	4,160	4,562	4,989	4,123	4,333	2,947	3,619	2,648	2,441	45,535
1889	2,256	2,229	4,180	4,758	4,920	4,402	4,808	4,309	3,567	3,430	2,857	4,539	46,255
1890	4,095	3,920	4,232	4,196	4,272	4,507	3,602	3,279	2,806	2,745	2,008	2,201	41,863
1891	2,217	4,320	3,300	3,761	4,205	4,135	3,618	4,041	4,860	3,798	3,261	4,368	45,884
1892	2,474	2,234	4,935	3,954	3,952	4,501	5,039	4,355	4,313	3,778	5,377	3,612	48,524
1893	3,695	3,822	4,810	5,741	5,729	5,173	4,532	4,196	4,973	3,876	3,775	3,256	53,578
1894	4,135	4,305	5,273	4,958	5,387	4,836	4,167	4,358	4,401	4,366	3,187	4,132	53,505
1895	4,571	2,947	5,886	5,638	5,513	4,559	4,464	4,134	5,140	3,966	3,512	3,804	54,134
1896	4,274	3,601	4,382	5,710	4,963	4,460	4,108	4,185	5,002	4,234	4,166	3,239	52,324
1897	2,662	3,742	5,490	5,215	5,020	4,663	4,687	4,238	4,637	4,376	3,557	3,436	51,723
1898	3,169	3,460	5,148	5,018	4,539	4,733	4,334	4,486	4,432	3,878	3,679	3,799	50,675
1899	4,449	3,343	5,044	5,356	5,058	4,664	4,348	4,913	3,748	......	......	......	a 40.923
	81,130	81,231	111,542	121,212	123,267	117,053	111,134	108,793	105,264	92,867	78,193	79,091	1,210,777
Average	3,245	3,250	4,462	4,662	4,741	4,502	4,274	4,184	4,049	3,715	3,128	3,164	b 47,444

a For 9 months.   b For 24 years.

HISTORY OF IRRIGATION.

Modern irrigation in the United States began in Salt Lake Valley, Utah, when the Mormons settled there in 1847. One of the first undertakings after reaching the valley was the diverting of the water of what is now known as City Creek and the irrigation of a few acres of land planted with seed brought with them on their long and perilous journey from Illinois.

Traces of irrigation antedating the Salt Lake Valley undertaking are to be found in Arizona in the systems (long since abandoned) of an extinct race of aborigines, and in southern California, where irrigation was practiced by the mission priests.

An historian of the Mormon Church describes the present site of Salt Lake City as follows:

A desolation of centuries, where earth seemed heaven forsaken, where hermit nature—watching, waiting—wept and worshipped God amid eternal solitude.

Charles Brough, in his Historical and Political Studies on Irrigation in Utah, says:

The transformation of this sterile waste, glistening with beds of salt, and soda, and deadly alkali, seemed impossible.

These quotations give an idea of how the conditions appeared to the first settlers. In the year 1848, 5,153 acres were put under irrigation,

and the amount of land under irrigation in this locality has since rapidly increased. The growth of Salt Lake City was very rapid, and in 1850 the population numbered 11,354. During this year there were over 16,000 acres under cultivation. In 1852 the assessed value of property was $400 per capita. To-day the city possesses a population of 70,000. The broad streets are lined with rows of stately trees and the comfortable homes are surrounded by luxuriant lawns.

The rural districts are populous; the farms are small and are characterized by an intensive and diversified form of agriculture. In the whole State of Utah the average size of the irrigation farms is 27 acres.

According to statistics gathered in 1894 by the State statistician, there were 2,195 farms in Salt Lake County, 90 per cent of which were cultivated by the owners. Of the total number of farms only 14 per cent were incumbered by mortgage.

Notwithstanding the success that has been attained, serious damage has occurred in places through the accumulation of seepage waters and alkali. Districts once successfully farmed have been abandoned and the attempts at reclamation have failed, because suitable methods have been wanting. Damaged lands are more apparent now than formerly, and demand for methods of preventing such damage and for reclaiming waste land is greater than ever before.

The earliest irrigation was principally on the east side of the Jordan River, the irrigation waters being obtained from the numerous small streams issuing from the canyons of the Wasatch Mountains. The canals, always small, were constructed by cooperative labor, cooperation being the watchword of the Mormons and even to the present time predominating in all lines of mercantile pursuits.

A number of farmers owning land along a stream joined together and by their collective labor constructed a canal that brought water to all of their farms. The distribution of the water was proportional to the amount of land owned by each. The advantage of this method was that it gave water to each farmer without expenditure of money and without waiting. The canals were crudely constructed and no provision was made against leakage. Water was turned into the canals in the spring and not turned out until fall, in some instances even running throughout the year. As a result the large amount of waste and seepage waters did much damage to lands lying below the neighborhood irrigated, and at the present time a large area of land immediately south of Salt Lake City and adjacent to the river is much affected by seepage waters and alkali.

On the west side of the Jordan River the earliest attempts at irrigation were on the Jordan meadows or river bottom lands, the water supply being obtained from the Jordan River by means of small canals. Subsequently the Brighton and North Point and the North Jordan canals were run upon the first terrace above the river, and following these were the South Jordan and the Utah and Salt Lake canals on the second and third benches, respectively.

As is frequently the case, the irrigation on the benches caused an accumulation of seepage and alkali on the river bottom land, so that much of it has been abandoned. The largest and most seriously damaged area, however, is just south of Twelfth Street road, and comprises a strip of land varying from half a mile to a mile and a half in width, and extending 10 miles west from the river. Here the seepage and surplus waters from the outer extremities of the Utah and Salt Lake, the South Jordan, and the North Jordan canals have collected to an alarming extent. Indeed, the damage has gone so far that a chain of lakes has formed, presenting a water surface of fully 1,000 acres. The area affected is not less than 10 square miles.

That portion of Salt Lake Valley west of the Jordan River which is at present under irrigation includes about 40 square miles, and covers a strip about 2 miles wide, bordering on the river and extending through Ts. 2 and 3 S., R. 1 W., together with another narrower portion at the north, which bends to the west through T. 1 S., Rs. 1 and 2 W., nearly to the point of the mountains. It consists mainly of terraces, one above another, and has a slope toward the river or to the north of 50 to 100 feet per mile.

In addition to the above-named canals there is the surplus canal, from which the North Point Consolidated Canal is taken. The latter conducts water to the low-level area north of the base line, but is little used for irrigating purposes because of the unsatisfactory results of applying water to this level, salty land.

The irrigation canals on this side of the river have an aggregate capacity of about 600 cubic feet per second, but less than half of this amount is required or used on the 25,000 acres under cultivation. On the low-level area, between Salt Lake City and the lake, many attempts have been made and much money expended in the endeavor to successfully irrigate the land; but, with a few minor exceptions, the attempts have all proved failures.

The canals are owned, for the most part, by the owners of the land under irrigation, and the only paid officer is the "water master," whose duty it is to attend to the equitable distribution of the water to the shareholders. At stated intervals, along the main canals, laterals are taken out to supply the farms along its course. Each lateral has a head gate, the opening or closing of which is controlled by the water master, and the size of the opening is varied according to the number of shares supplied by the lateral and the total water supply for the canal. If the water supply is plentiful, the gates usually remain with a certain-sized opening throughout the season, and the water is permitted to flow continuously. Each shareholder is entitled to use all of the water flowing in the lateral for a stated number of hours and at stated intervals, according to a schedule agreed upon at the beginning of the season.

SOILS.

The area surveyed in 1899 includes all of that part of Salt Lake Valley lying west of the Jordan River, and is equal to about two-thirds of the entire valley. It extends westward to the foothills of the Oquirrh Mountains and the Great Salt Lake and northward to the lake. The area, roughly estimated, is 14 miles east and west by 28 miles north and south at its greatest extremes, and includes over 250 square miles.

Topographically the area varies in elevation from the present level of the lake, which is 4,170 feet above sea level, to about 4,700 feet at the foothills. A contour taken 50 feet above the lake would include the northern half of the district, which is comparatively level. The portion above such a contour inclines toward the mountains at the rate of from 50 to 100 feet per mile. The drainage is into the Jordan River or directly into the lake.

The soils have been formed by material brought down from the mountain sides and by sediments from the ancient Lake Bonneville, all of which have been materially modified by inflowing streams from the mountains and by the vacillating shore of the lake. Soils formed in this way are usually heterogeneous, and these soils form no exception to the rule. In the lower part of the valley the sediment is very deep, no rock or gravel being found at a depth of a hundred or more feet. As we get near the foothills, gravel and rock are plentiful and often crop out at the surface. Here there is little or no lake sediment apparent.

The soils are fertile, but in the natural condition support only a meager vegetation, because they are either too dry or too salty. On the higher portions, where there is little salt present, sagebrush forms the chief growth, while in the lower areas, where there is more moisture and much salt, salt-loving perennials, such a greasewood and "mutton sas," abound.

The following classification of the soils is based on the judgment of the field experts, typical samples of the various types being sent to the laboratory and analyzed, not as a basis for classification, but in order to obtain an explanation of certain characteristics as they appeared in the field.

The chief basis of the classification is texture, as determined by the feeling and appearance of the soil, and it will be seen by studying the analyses of samples of the different types that the judgment of the experts is quite as accurate as the analysis itself.

The classification is based chiefly on the characteristics of the first foot in depth of the soil, although the underlying stratum is sometimes considered, as in the case of the Bingham gravelly loam, where the gravel is sometimes absent in the top foot, but occurs in the second or third foot.

The soils have been classified under eight types, in the order of the magnitude of their respective areas, as follows:
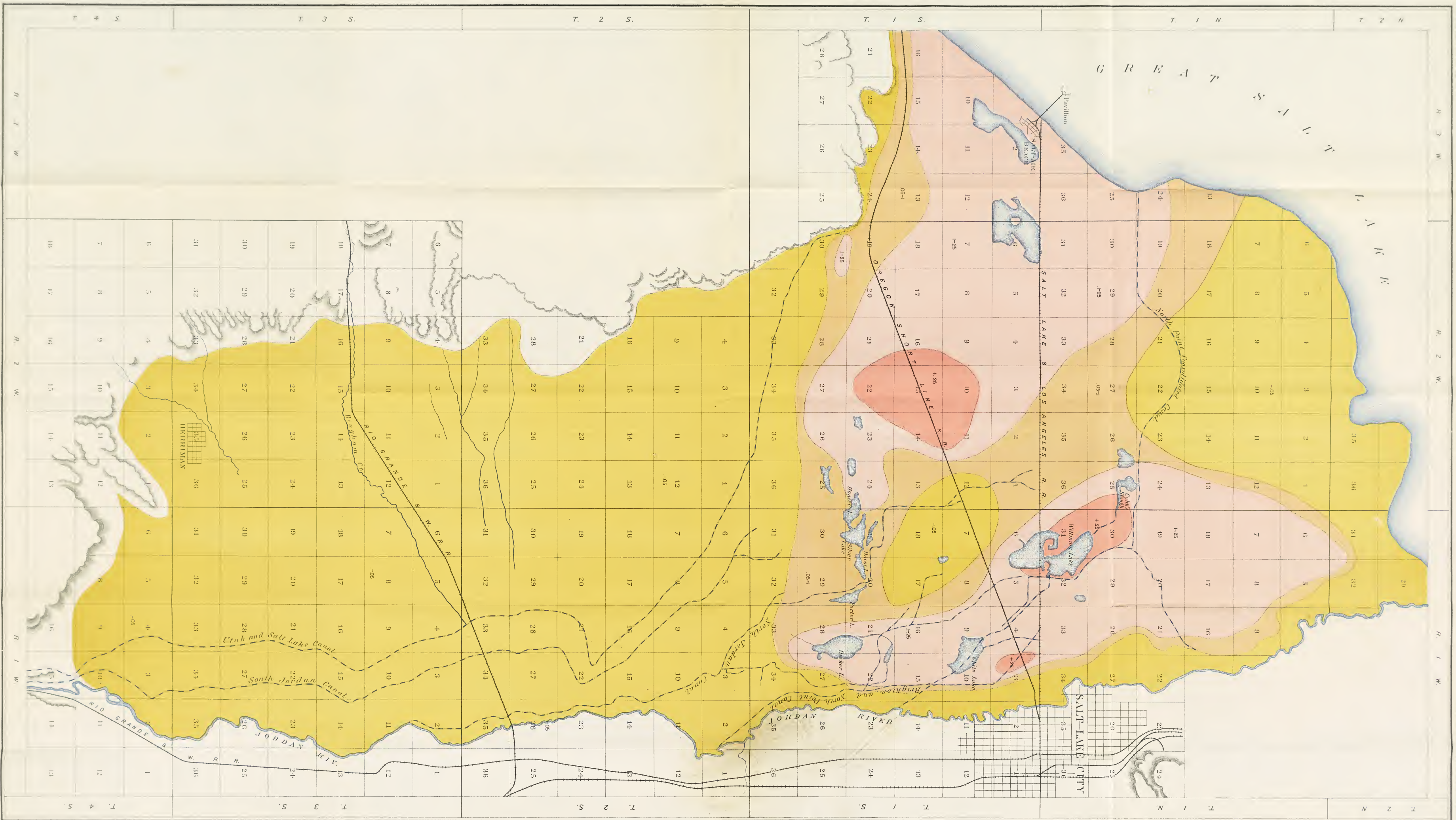
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GREAT SALT LAKE

SALT LAKE CITY

JORDAN RIVER

Rio Grande W. R. R.

Oregon Short Line R. R.

Salt Lake & Los Angeles R. R.

Utah and Salt Lake Canal

South Jordan Canal

North Jordan Canal

Brighton and North Point Canal

North point forced water Canal

HERRIMAN

Salt Air Beach

Pavilion

Cobble Swamp

William Lake

White Lake

Decker L.

Silver Lake

T. 4 S.   T. 3 S.   T. 2 S.   T. 1 S.   T. 1 N.   T. 2 N.

R. 3 W.   R. 2 W.   R. 1 W.

LEGEND

+25	Over .25 per cent
.1–.25	From .1 per cent to .25 per cent
.05–.1	From .05 per cent to .1 per cent
–.05	Less than .05 per cent

1. Jordan sandy loam.
2. Bingham gravelly loam.
3. Jordan loam.
4. Jordan clay and clay loam.
5. Jordan meadows.
6. Jordan sand.
7. Bingham stony loam.
8. Salt Lake sand.

JORDAN SANDY LOAM.

This loam, shown on the soil map by the orange color, comprises about 30 per cent of the entire district, and is the most important of the various types of the soil, both in extent and quality. It is a light, sandy loam, varying from one to several feet in depth, the texture of which is shown in the accompanying table of mechanical analyses.

Mechanical analyses.

No.	Locality.	Description.	Salt, as determined in mechanical analysis.	Moisture in air-dry sample.	Organic matter.	Gravel, 2 to 1 mm.	Coarse sand, 1 to 0.5 mm.	Medium sand, 0.5 to 0.25 mm.	Fine sand, 0.25 to .1 mm.	Very fine sand, 0.1 to 0.05 mm.	Silt, 0.05 to 0.01 mm.	Fine silt, 0.01 to 0.005 mm.	Clay, 0.005 to 0.0001 mm.
	Jordan sandy loams 0 to 12 inches in depth.		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
4303	SW.¼ sec. 17, T. 1 N., R.1 W.	Dry level land..	0.49	1.18	1.84	0.16	4.17	11.40	27.87	17.76	23.49	2.64	8.79
4311	SE.¼ sec. 31, T. 2 N., R.1 W.	Low level land.	.41	.94	2.17	1.10	3.28	7.80	15.23	23.46	33.06	2.80	9.47
4309	C. sec. 24, T. 1 S., R.2 W.	Dry level land..	1.69	1.62	9.20	0.00	.12	.61	26.87	23.55	23.30	3.59	10.87
4369	S. C. sec. 17, T. 1 S., R.1 W.	.....do..........	1.50	1.45	3.31	T.	.28	.95	8.84	39.31	29.44	3.28	11.74
4310	C. sec. 20, T.1 N., R.2 W.	.....do..........	1.09	1.79	5.25	.13	3.96	9.61	20.13	16.43	26.36	2.59	13.37
4297	N. C. sec. 27, T.1 N., R. 2 W.	.....do	.89	1.55	4.57	.18	3.42	10.01	23.74	15.65	24.38	2.80	13.55
365	NE. C. sec. 16, T. 2 S., R.1 W.	Alfalfa, irrigated.	.30	1.95	5.42	T.	.77	4.98	3.11	26.82	35.85	3.87	14.58
366	S. C. sec. 1, T. 1 S., R.2 W.	Trees, irrigated.	.44	1.27	4.05	.67	1.06	1.43	9.11	29.85	33.08	4.75	15.03
	Subsoils under Jordan sandy loams.												
4370	Loam 24 to 36 inches.	Under 4369.....	1.08	1.49	5.61	T.	.48	1.63	8.61	27.12	29.42	2.60	22.43
4371	Sandy loam 36 to 60 inches.	.....do..........	.66	.99	4.24	.....	T.	.82	5.90	42.41	30.33	2.79	13.10
4367	Loam 12 to 24 inches.	Under 4366.....	.44	1.27	5.16	.35	1.11	1.40	5.84	30.05	31.11	5	18.21
4368	Fine sand=sandy loam 24 to 48 inches.	.....do..........	.46	.90	3.94	T.	.31	.34	3.10	46.38	32.82	2.72	9.54

The analyses of the eight samples of soil in the above table, the samples being taken from the first foot in depth, probably represent the range in texture for this type of soil. The clay content is comparatively low, ranging from a minimum of 8.79 per cent to a maximum of 15.03 per cent with a mean of about 12.2 per cent, which may be taken as representing the average clay content of this type of soil. By far the larger part of the separations occur under the heads of very

fine sand and silt, which give an average of 24.1 and 28.6 per cent, respectively.

The soil varies somewhat in underlying strata, but the most usual profile is 2 feet of sandy loam, 1½ feet of loam, and 1 foot of fine sand, underlaid by clay to considerable depth. In the above table Nos. 4370 and 4371 show the texture of the loam and sandy loam (the latter approximating very fine sand) which underlie soil No. 4369, while Nos. 4367 and 4368 represent the loam and fine sand underlying soil No. 4366. The clay, which usually occurs at a greater depth than these samples represent, corresponds in texture to the analyses given for the same under Jordan loam on page 95. Subsoils of this texture permit a ready movement of the ground water, and should therefore be easily under-drained by placing lines of tiles 150 feet apart.

As a rule the Jordan sandy loam overlies the Jordan loam, on which it generally borders, and it occurs mostly in the irrigated district and the low land to the north. That portion of it lying above the irrigation canals, as well as that in the irrigated district wherever the water table is 10 or more feet below the surface, is free from any excessive amount of salts. On the low area to the north, however, it generally contains considerable salt, especially in the lower depths. The native vegetation on this part of it consists mainly of greasewood and shad scale (perennial bushes growing from 1 to 4 feet in height) on the drier and less salty portions; and of mutton sas, salt grass, and various small salt-loving annuals on the moist and more salty places.

The accompanying table shows the per cent of salt in solution when the soil is saturated with water for various depths and places in the Jordan sandy loam, the percentage being calculated on the water-free soil.

Table showing the soluble salt content at saturation for various places and depths in Jordan sandy loam.

Number of boring.	Depth, in feet.									Depth to stand-ing water.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	
	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Feet.
200	0.06	0.05	0.05	0.06	0.08	0.08	0.10	0.11	0.11	10+
206	.06	.05	.06	.05	.09	.15				20
16	1.51	1.17	.74	.50	.62	.72				4
99	.76	.63	.40	.35	.29	.28				3½
300 a	.18	.15	.19	.25	.25	.20				4
651	.35	....	1.02	....	1.06	....				4
629	.11	.54	.88	b. 33	b. 35	1.64				6+
644	.14	.68	1.01	1.12	1.39	2.00				6+
517	.40	....	.76	....	1.04	....				7
626	.09	.48	.85	1.10	1.54	2.22				6+

a Irrigated.   b Sand pocket.

Borings Nos. 200 and 206 represent about the mean salt content of this type of soil on the good irrigated land. Here the salt rarely exceeds 0.1 per cent above a depth of 5 feet. While there is a gradual increase in the salt as we go down, it never occurs to an alarming

NATURAL VEGETATION OF GREASEWOOD AND SALTBUSHES ON JORDAN SANDY LOAM.

This land in its natural state is adapted only to the grazing of sheep.

extent, although there may be sufficient to wash out into seepage areas below, and thus cause damage by its accumulation.

Borings Nos. 16, 99, and 651 show the condition on the low land where the water table is within 4 or less feet of the surface. Here there is a comparatively large amount of salt present and Nos. 16 and 99 show an accumulation in the surface foot, which is usually the case when the water is 3 feet or less below the surface. These borings were made during the driest part of the year, and it is probable that the water table is nearer the surface during the time of the year when more rain falls.

Boring No. 300 is in a favorable location on the low land where the water, before irrigation was undertaken, was nearly 10 feet below the surface. It has been irrigated for three years and is now planted in trees. The salt content is fairly uniform in its distribution and, while not present in great quantity, there is sufficient to cause serious trouble if allowed to accumulate in the surface portion of the soil. This it is likely to do if the water table rises much above its present level.

Borings No. 629, 644, 517, and 626 are representative of the amount and vertical distribution of the salts for the unirrigated low-land part of this type of soil, where the depth to standing water is 6 or more feet, which is usually the case. In these samples the aggregate amount of salt to the depth of 6 feet is considerable and will correspond to the area shown on the map by an appropriate color, where the salt content to a depth of 5 feet ranges from 0.6 to 1 per cent. A small portion of this type of soil, however, falls within another area on the map, where the salt content exceeds 1 per cent, while, on the other hand, some of it falls in the blue area, with less than 0.6 of 1 per cent. The first foot usually carries a relatively small amount of salt and indicates that crops could be successfully grown. As we go deeper, however, the amount of salts increases very rapidly and the second foot is usually about the limit for alfalfa, while the third foot almost invariably contains too much to permit the growth of any agricultural crops. At 6 feet there is usually about 2 per cent of salt.

This distribution of the salts probably occurs because the rains wash them downward more rapidly than they are returned toward the surface by evaporation. If irrigation water were applied, the salts would continue to move downward, provided the water table remained at its present depth. Unfortunately, however, the application of water invariably causes a rise of the water table, and if the application be continued over a considerable area the water table comes sufficiently near the surface to cause excessive surface evaporation, which results in an upward movement of the salts and their consequent accumulation at the surface. The present surface conditions as regards the amount of salt are fairly good over considerable areas, but in order to improve or even maintain these conditions under irrigation thorough underdrainage is imperative.

The Jordan sandy loam is easily cultivated and is sufficiently fertile to produce almost any class of crops. It forms the most valuable portion of the low salty area, because of the ease with which it may be reclaimed by underdrainage and washing. Owing to the light texture of the subsoil, the lines of drains could be farther apart than in the heavier soils, and it would therefore be less expensive to drain.

The diagram on page 93 (fig. 9) shows sections in various directions in the valley and illustrates the constitution of the soils to a depth of 6 feet.

BINGHAM GRAVELLY LOAM.

This type of soil is next in extent to the Jordan sandy loam, and comprises 60 square miles, or 24 per cent, of the entire district. Excepting about 2,000 acres immediately under the Utah and Salt Lake Canal, principally in the southern part of T. 1 S., R. 2 W., it all lies above the irrigation canals and is too elevated to be irrigated by any of the present water supply. There has been a scheme proposed for raising part of the water passing through the Jordan Narrows by hydraulic means and constructing another canal above and parallel with the Utah and Salt Lake Canal. The height to which it would be profitable to raise water for irrigation purposes by such means would take in only a narrow strip of this upland, owing to the steepness of the slope toward the mountains.

At Herriman there are about 100 acres irrigated by water taken from Butterfield Creek, and in the northwestern part T. 2 S., R. 2 W., there are a few small springs which serve to irrigate a very limited area. There are also a few small farms along Bingham Creek irrigated by its waters.

During freshets considerable water comes down from the canyons of the Oquirrh Mountains, and, in a few instances, some of it is diverted and used for irrigation. This, however, is very unsatisfactory, because at times when water is most needed no water is to be had. The only possible means of successfully irrigating any considerable area of this land is by storing the water from the mountain streams in reservoirs constructed for that purpose.

The Bingham gravelly loam comprises the area shown on the soil map by the brown color. It is always underlaid by gravel at within 3 feet of the surface, and the small gravel generally papears at the surface in greater or less quantities.

The following table gives the mechanical analyses of four samples of this soil to 12 and 15 inches in depth.

PLATE XII.
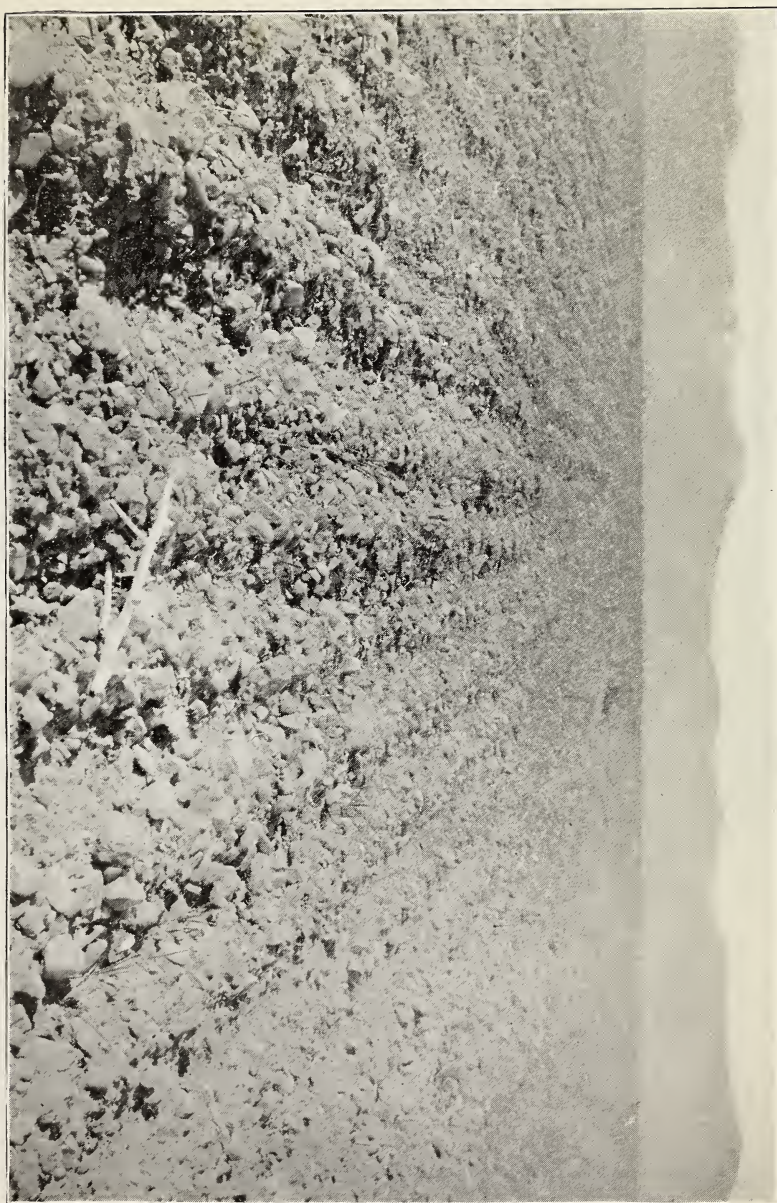
BINGHAM GRAVELLY LOAM—GRAVEL 1 INCH IN DIAMETER.

This type of soil is dry-farmed to wheat and in favorable seasons produces fair yields.

G R E A T   S A L T   L A K E

Pavilion

SALT AIR BEACH

UNDERGROUND WATER MAP

SALT LAKE CITY

Rio Grande W. Co.
W. G. R. R.
Bingham Co.

Utah and Salt Lake Canal
South Jordan Canal
RIO GRANDE & W. R. R.
JORDAN RIVER

North Jordan Canal
Brighton and North Point Canal
JORDAN RIVER

OREGON SHORT LINE
SALT LAKE & LOS ANGELES R. R.
North Point and Riter Canal

Sheep Lake
Decker L.
Hunter L.
Riter L.
Williams Lake
Calders Canal
White Lake

DESERET

LEGEND

	Water over 10 ft. deep
	Water 3 ft. to 10 ft. deep
	Water less than 3 ft. deep

Fig. 9.—Sections in Salt Lake Valley along lines marked on sketch map, page 103. (*S* = sand; *Ssc* = sandy loam; *Sc* = loam; *C* = clay; *Gr* = gravel.)

Section A–A.

Section B–B.

Section C–C.

LEVEL OF JORDAN RIVER

LEVEL OF JORDAN RIVER

LEVEL OF LAKE

Mechanical analyses of Bingham gravelly loam soils.

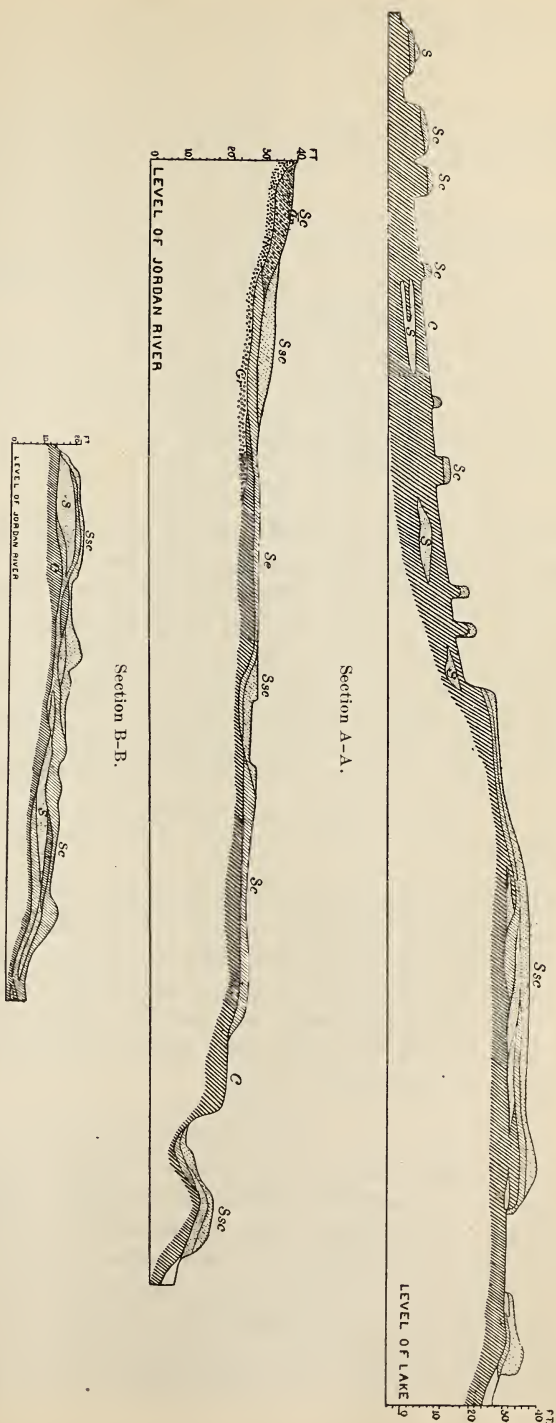| No.	Locality.	Description	Moisture in air-dry sample.	Organic matter.	Fine gravel, 2 to 1 mm.	Coarse sand, 1 to 0.5 mm.	Medium sand, 0.5 to 0.25 mm.	Fine sand, 0.25 to 0.1 mm.	Very fine sand, 0.1 to 0.05 mm.	Silt, 0.05 to 0.01 mm.	Fine silt, 0.01 to 0.005 mm.	Clay, 0.005 to 0.0001 mm.
			Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
4362	SW. ¼ sec. 15, T. 3 S., R. 2 W.	Rolling land 0 to 15 inches, 25.5 per cent coarse gravel.	2.25	3.96	1.50	2.71	5.81	8.87	27.93	28.08	5.13	13.53
4363	S. C. sec. 24, T. 2 S., R. 2 W.	Rolling land 0 to 15 inches, 9 per cent coarse gravel.	2.90	4.16	0.66	1.77	7.71	8.50	28.71	22.19	4.38	15.98
4312	SW. ¼ sec. 2, T. 2 S., R. 2 W.	Rolling land 0 to 12 inches, 54.5 per cent coarse gravel.	2.39	4.53	7.57	2.64	2.88	7.29	13.06	37.12	4.34	18.15
4313	SE. ¼ sec. 34, T. 3 S., R. 2 W.	Rolling land 0 to 15 inches, 4.4 per cent coarse gravel.	3.04	5.06	.33	.77	2.48	4.09	15.73	38.91	5.08	22.66

The analyses show the texture of the fine earth after all gravel larger than two millimeters in diameter has been taken out. The clay ranges from 13.5 to 22.6 per cent of the fine earth. The coarse gravel varies from 4.4 to 54.5 per cent. The gravel is small and more or less rounded and interferes little with the cultivation of the soil. Below 3 feet, and sometimes at even a less depth, the gravel becomes large and occasionally gives place to bowlders and rock. The most usual profile to 6 feet in depth is 18 inches of gravelly loam, underlaid by large gravel. This type of soil is usually free from noticeable amounts of salt, as will be seen by referring to the salt map. The native vegetation consists largely of sagebrush, with some rabbit bush, grass, tumble weeds, etc.

A considerable percentage of this type of soil is dry farmed to wheat. As a rule, the yield is small, but in years of abundant rainfall it sometimes exceeds 20 bushels per acre. The land slopes rapidly toward the mountains and has many deep washouts, which seem much larger than would be required for the natural escape of the drainage waters. These were probably formed by cloudbursts, which at some period visit most of the areas in the Bonneville Basin.

JORDAN LOAM.

This type of soil, while ranking third in extent, is perhaps second in importance, as it mostly lies within reach of the present irrigation water supply. It comprises about 50 square miles, or 20 per cent of the total area, and four-fifths of it lies below the present canal systems. Of this portion, however, there are numerous isolated areas, occurring in the area of clay flats near the shore of the lake, which, owing to their irregular forms, small size, and location would be relatively expensive to irrigate. The main body of this type of soil, how-

ever, could be easily irrigated and, as demonstrated by that portion now under cultivation in the irrigation district, would prove excellent land if put in proper condition.

This type of soil is shown on the soil map by the areas in solid red. It varies much in depth and underlying strata; the most usual profile, however, is 3 feet of loam, underlaid by clay which contains frequently pockets or strata of sand.

The accompanying table of mechanical analyses shows the texture of the surface foot in six localities and the character of the subsoil underlying two of them.

Mechanical analyses of Jordan loams.

No.	Locality.	Description.	Salt as determined in mechanical analysis.	Moisture in air-dry sample.	Organic matter.	Gravel, 2 to 1 mm.	Coarse sand, 1 to 0.05 mm.	Medium sand, 0.5 to 0.25 mm.	Fine sand, 0.25 to 0.1 mm.	Very fine sand, 0.1 to 0.05 mm.	Silt, 0.05 to 0.01 mm.	Fine silt, 0.01 to 0.005 mm.	Clay, 0.005 to 0.0005 mm.
			Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
4331	N W. C. sec. 34, T. 1 N., R. 2 W.	Dry level land	0.80	1.49	3.72	0.31	0.61	2.51	7.03	26.95	37.42	4.	14.70
4318	S. C. sec. 27, T. 3 S., R. 1 W.	Good alfalfa land irrig.	.56	2.30	5.05	.12	.16	.38	2.62	20.92	37.73	6.73	22.58
4324	S. C. sec. 18, T. 1 S., R. 2 W.	Low, wet by springs.	2.38	2.39	14.13	.10	.47	1.08	2.68	12.45	28.59	12.98	23.16
4325	NE. ¼ sec. 35, T. 1 N., R. 2 W.	Dry level land	.81	2.35	4.89	T.	.17	.64	4.66	20.68	36.23	5.99	23.51
4364	N. C. sec. 4, T. 1 S., R. 2 W.	.....do..........	1.08	2.10	6.81	1.57	2.42	3.23	5.67	14.22	29.96	6.49	27.66
4336	N W. ¼ sec. 8, T. 1 N., R. 2 W.	Low uneven land	1.76	1.07	8.57	T.	.56	1.25	7.45	33.70	12.46	1.06	31.80
	Subsoils under Jordan loams.												
4332	Loam 12 to 24 inches.	Under 4331	1.16	1.37	9.41	T.	1.47	2.10	6.53	24.81	30.58	2.38	21.04
4333	Very fine sand 24 to 36 inches.	.....do	.95	1.03	6.83	.....	.11	.66	7.78	42.67	27.04	1.85	11.91
4334	Sand and clay 36 to 48 inches.	.....do..........	1.25	.93	5.64	3.78	2.91	9.33	17.56	17.97	24.18	2.40	13.63
4335	Clay loam 48 to 72 inches.	.....do..........	1.59	2.18	8.16	1.26	.88	1.16	2.40	13.38	35.49	4.52	28.37
4372	Clay loam 12 to 24 inches.	Under 4364	1.74	2.64	9.22	.49	1.02	2.65	5.08	11.87	24.63	7.10	33.47
4372a	Clay loam 24 to 36 inches.	.....do..........	2.24	2.15	11.21	3.24	2.52	2.49	2.34	5.88	23.83	8.64	33.14
4373	Clay 36 to 48 inches.	.....do..........	2.24	2.10	10.23	T.	.41	.26	.41	7.33	24.46	9.23	44.38

The clay content varies from a minimum of 14.7 per cent to a maximum of 31.8 per cent. The latter amount is rather high to be classed as a loam, 30 per cent being usually taken as the upper limit for this class. This sample, however, was easily classed as a loam by the observer in the field, and the fact that it contains a lower percentage of silt and fine silt than any of the other samples analyzed for either this or the two preceding types of soil accounts for the apparent conflict between the analysis and the field judgment. The silt content, being unusually low, counteracts the effect of part of the clay, and therefore gives the sample the characteristics of loam. The mean clay content of 23.9 per cent for these six samples may be taken as representative of

this type of soil. The other large separations are under the heads of very fine sand and silt, which give 21.5 and 30.4 per cent respectively. The first four separations show a very small percentage in any of the samples.

Samples Nos. 4332–35, inclusive, show the texture of the subsoil to 6 feet in depth under soil No. 43 31. The second foot is also a loam, but heavier than the first, which is on the border line between Jordan sandy loam and Jordan loam; next comes very fine sand, which continues about two-thirds of the way through the fourth foot, and below this is clay loam. This character of subsoil, while common under Jordan loam, is perhaps more characteristic of the first type of soil.

Samples Nos. 4372 and 4373 show the texture of the subsoil under soil No. 4364. Here the second and third feet are clay loam and the fourth foot clay. This is more characteristic of this type of soil than is the former subsoil, excepting that the overlying loam is of less depth than the average. Subsoils of this character are so heavy that ordinarily they would be rather expensive to drain, on account of the short intervals at which lines of tiles would need to be laid in order to prove effective.

The field observations here, however, show that the clay or clay loam subsoil is most usually inlaid by strata of fine sand varying from a fraction of an inch to a foot or more in thickness. While these strata are continuous for only short distances, yet they occur at such frequent intervals that they would undoubtedly be of material assistance if under-drainage were undertaken.

Soil No. 4324 occurs in an area wet by large springs and producing a luxuriant growth of salt grass, which accounts for the high percentage of organic matter. The apparently high percentage of organic matter in the heavier samples is probably in part water of crystallization, which is only driven off by temperatures higher than are required for moisture determinations.

On the lowland the Jordan loam lies slightly lower than the sandy loam. It has the water-table rather near the surface and carries a higher percentage of salt.

The accompanying table gives the percentage of salt in each foot to a depth of 6 feet for various places in this type of soil.

Table showing the per cent of salts at saturation at various places and depths in Jordan loam.

[Percentage calculated on water-free soil.]

No. of boring.	Depth in feet.							Depth to standing water.
	1.	2.	3.	4.	5.	6.	8.	
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Feet.
275	0.07	0.07	0.08	0.09	0.10	0.07		10+
149	.05	.05	.06	.07	.07			
447	.58	.23	.19	.19	.14	.18		1
138	.49	.21	.18	.16	.16	.17		3
127	.58	.41	.24	.15	.16	.16		3
375	2.07	1.44	1.13	.86	.82	.92		4½
623	.11	.09	.23	.54	.88	81	0.67	5½
624	.38	.95	1.17	1.38	2.04	2.36		6
343	.74	1.38	1.65	2.09	2.09	2.21		5½
649	1.43	2.37	2.60	3.45	3.66	3.37		6

Borings Nos. 275 and 149 are typical of the favorable conditions for this type of soil in the irrigated district. Nos. 447, 138, and 127 are representative of the conditions in the southern part of T. 1 S., R. 1 and 2 W., where seepage water has caused an abandonment of the land for farming. Here the water table lies within 3 or less than 3 feet of the surface, and while the total salt content to a depth of 6 feet is only about 0.25 per cent, yet in the surface foot it has accumulated to such an extent as to be fatal to some crops. By removing the water the soil would soon return to a productive state.

Boring No. 375 is in a low level area which is watered by large springs. At the time this determination was made the water had been turned off, and the water table was 4½ feet below the surface. Ordinarily it is much nearer the surface than this, and, in fact, the surface is frequently covered by water. The salt content is high and shows an accumulation at the surface, this being always a result of wetness. Nos. 623, 624, 343, and 649 show the range in salt content and its usual distribution on the lowland part of this type of soil when the water table is more than 4 feet below the surface. They all show the minimum amount in the surface foot, and a gradual increase as the depth increases. No. 623 shows an unusually small amount, 649 an excessive amount, and 624 and 643 normal amounts for this type of soil.

A comparison of the soil and salt maps shows that most of this type of soil which is on the lowland falls within the slate colored area on the salt map—i. e., it contains from 1 to 3 per cent of salt to a depth of 5 feet. Excepting about 2 square miles near the mouth of the Jordan River, none of it falls into the class containing more than 3 per cent; but on the other hand a small per cent falls in the class containing 0.6 to 1 per cent.

Like the Jordan sandy loam, this type of soil also frequently shows a comparatively small amount of salt in the surface foot, but as we descend it increases rapidly, and when the soil is put under irrigation the salts soon accumulate at the surface, unless by some means the water table is kept down and the surface evaporation reduced to a minimum by the best cultivation or by shading crops.

The larger percentage of this type of soil is capable of reclamation by underdrainage and washing, but at a somewhat greater outlay than would be required for the Jordan sandy loam.

JORDAN CLAY AND CLAY LOAM.

The next type of soil in order of extent is the Jordan clay and clay loam, which comprises about 35 square miles, or 14 per cent of the whole area. Excepting about 1,500 acres, one-half of which lies west of Williams Lake and the remainder southwest of Decker Lake, this type of soil lies from 4 to 8 feet lower than the land immediately adjoining. It is level and wet, and rarely contains any vegetation. It forms what was formerly the floors of lagoons near the shore of the lake and

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often extends far back into the higher and better land. In other places it assumes the form of draws extending like wide irregular canals back into the land for miles. Its distribution is shown on the soil map by the blue color.

The accompanying table gives the mechanical analyses of two samples of soil and the subsoil under one of them to 6 feet in depth.

Mechanical analyses of clay and clay loam soils.

No.	Locality.	Description.	Salt as determined in mechanical analysis.	Moisture in air-dry sample.	Organic matter.	Gravel, 2 to 1 mm.	Coarse sand, 1 to 0.5 mm.	Medium sand, 0.5 to 0.25 mm.	Fine sand, 0.25 to 0.1 mm.	Very fine sand, 0.1 to 0.05 mm.	Silt, 0.05 to 0.01 mm.	Fine silt, 0.01 to 0.005 mm.	Clay, 0.005 to 0.0001 mm.
			Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
4345	C. S. 18, T. 1 N., R. 2 W.	Salt flat	8.89	....	11.51	3.94	4.91	2.92	2.28	14.10	19.15	4.23	25.67
4351	S. 30, T. 1 N., R.1 W.	Low level land	2.04	2.63	6.39	.77	.90	2.03	4.37	20.68	27.46	4.35	28.18
	(Subsoil under 4345.)												
4346	Depth 12 to 24 inches.	Clay loam	11.47	2.10	13.65	7.19	6.17	4.94	3.52	7.28	22.78	4.47	16.86
4347	Depth 24 to 36 inches.	Yellow clay	7.82	11.02	12.96	4.14	1.88	2.66	1.16	5.47	23.53	3.45	26.87
4348	Depth 36 to 48 inches.	Red clay	5.92	8.24	8.43	2.58	1.06	.64	.54	8.41	27.19	3.74	35.23
4349	Depth 48 to 60 inches.	.....do.........	6.53	10.20	9.50	8.58	.41	.23	.28	3.27	24.02	3.38	33.50
4350	Depth 60 to 72 inches.	.....do.........	5.02	.....	5.32	.51	.29	.32	.50	14.42	30.04	10.80	33.74

Sample No. 4351 shows the texture of the small upland area just west of Williams Lake. It is very similar to the Jordan loam, which lies adjacent, but is slightly lower and somewhat heavier in texture. Its salt content to a depth of 6 feet is shown under boring No. 162 in the table giving salt content. The total salt content does not differ materially from that in the adjacent Jordan loam, but it shows an accumulation in the upper portions, which is not the case with the latter, where the water table lies at 6 feet, as it does here. The probabilities are that the water table is much higher under this soil during a portion of the season.

No. 4345 shows the texture of the clay loam of the flats, 20 per cent of this sample being under the heads of organic matter, and salt. Therefore the clay content should be increased from 25.67 to over 30 per cent, in order to show the real per cent of clay present in the soil alone. The subsoil beneath this is shown in Nos. 4346-50.

The accompanying table shows the per cent of salt for this type of soil:

Salt content at saturation for various places and depths in Jordan clays and clay loams.

[Percentage calculated on water-free soil.]

Number of boring.	Depth in feet.										Depth to standing water.
	1.	2.	3.	4.	5.	6.	8.	10.	12.	15.	
	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Feet.
132	0.14	0.11	0.12	0.13	0.12	0.12	....	....	....	....	2
162	1.18	1.23	1.12	.79	.68	....	....	....	....	....	6
355	5.58	4.95	6.30	6.41	5.22	....	4.44	2.96	1.86	.88	3
645	4.50	5.06	6.03	....	7.82	....	....	....	....	....	1½
646	10.60	9.80	11.40	10.30	9.80	9.30	....	....	....	....	2

Boring No. 132 gives the salt for each foot to 6 feet in depth for the area southwest of Decker Lake. The water table at the time of making this boring was only 2 feet below the surface, but the determination shows only a slight tendency to an accumulation of salt at the surface. In other portions of this area, however, the accumulation of the salt at the surface has caused the land to be abandoned.

Nos. 355, 645, and 646 give the salt content for three places in the barren clay loam and clay flats, and the amount present is simply astonishing. The above determinations show a range of from 4.5 to 11.4 per cent of salt in solution at saturation in the upper 6 feet of soil, and it is probable that at such concentration some of the salts may remain undissolved and are therefore not shown by the electrical method, which was used in their determination. Below 6 feet in depth there is a gradual diminution in the salt content, and in boring No. 355 it is only 0.88 per cent at 15 feet in depth. Boring No. 646 shows a very high salt content, the average to 6 feet in depth being 10.2 per cent. Allowing 70 pounds as the weight of a cubic foot of this soil, the amount of salt present, to a depth of 6 feet, in one square mile would amount to approximately 1,200,000,000 pounds. To the average mind such large numbers give no adequate idea of the real amount. By reduction we find that the 1,200,000,000 pounds equal 600,000 tons, which, at the rate of 20 tons each, would fill 30,000 cars. At 20 cars to the train this would equal 1,500 trains, or a continuous train of cars 180 miles long.

The agreement in area of this type of soil and the areas on the salt map showing 3 or more per cent of salt is almost identical. This type of soil being low, wet, salty, and of a clay nature, is not worthy of any notice for agricultural purposes at the present time. Those parts of it that extend far back into the better land form good drainage outlets for the latter and with very little improvement would serve to conduct drainage water to the lake.

JORDAN MEADOWS.

The Jordan Meadows comprise about 12 square miles, or 4.8 per cent of the entire area. They lie as a narrow strip, from a few rods to three-quarters of a mile in width, bordering on the Jordan River, and their usual elevation is only a few feet above the water in the river. Both the soil and the subsoil vary much in texture. The soil, however, is generally either a sandy loam or a loam about 2 feet in depth, which is underlaid by 2 feet of clay and this in turn is underlaid by sand and gravel. The soil is usually black, on account of the large amount of organic matter that it contains.

The following table shows the mechanical analyses of the soil from three places:

Mechanical analyses of Jordan Meadows soils.

No.	Locality.	Description.	Salt as determined in mechanical analysis.	Moisture in air-dry sample.	Organic matter.	Gravel 2 to 1 mm.	Coarse sand 1 to 0.5 mm.	Medium sand 0.5 to 0.25 mm.	Fine sand 0.25 to 0.1 mm.	Very fine sand 0.1 to 0.5 mm.	Silt 0.05 to 0.01 mm.	Fine silt 0.01 to 0.005 mm.	Clay 0.005 to 0.0001 mm.
			Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
4338	W. C. sec. 22, T. 1 N., R. 1 W.	River bottom, 0 to 24 inches.	1.05	1.18	5.90	T.	3.71	8.42	15.91	36.07	15.75	1.74	9.65
4337	SW. C. sec. 14, T. 1 S., R. 1 W.	River bottom, 0 to 12 inches.	1.96	1.89	9.23	T.	1.57	1.72	7.16	31.30	26.76	3.34	15.53
4339	E. C. sec. 14, T. 3 S., R. 1 W.	River bottom, 0 to 12 inches.	1.68	4.85	11.61	.21	.82	3.01	6.87	19.41	30.84	5.96	16.92

This type of soil was the first irrigated on the west side of the river, but wherever irrigation has been practiced above this land the seepage waters have come down and caused much damage. At present very little of it is farmed, but it often furnishes good pasture.

The accompanying table gives the salt content to a depth of 6 feet in three localities. The salt while not present in excessive amounts is sufficiently high to be harmful and is sometimes even fatal to ordinary crops. There is a tendency for it to accumulate at the surface.

Salt content at saturation for various depths and places in Jordan meadows.

[Percentage calculated on water-free soil.]

No. of boring.	Depth in feet.						Depth to standing water.
	1.	2.	3.	4.	5.	6.	
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Feet.
5	0.37	0.76	0.40	0.31	0.36	0.35	3½
637	0.55	0.51	0.49	0.55	0.35	0.30	6
281	0.73	0.67	0.36	0.29	0.27	0.18	5

JORDAN SAND.

These sands constitute a marginal area along the bluffs just above the Jordan meadows, and are found in a few isolated areas on the upland. They are shown on the soil map in yellow. It is fine sand

PLATE XIII.

BINGHAM STONY LOAM, LOOKING TOWARD THE LAKE SHORE.

This stony loam can not be cultivated.

usually to a depth of 6 feet or more, although occasionally occurring as an overlying stratum only 1 or 2 feet in depth, covering sandy loam or loam.   In places it drifts about as dunes, and is usually so located as to be difficult to irrigate, therefore it is not much used for agricultural purposes.   Where irrigated it requires large amounts of water to cover any considerable distance, and as a consequence, accumulations of seepage waters on low adjacent areas are the rule.   Owing to the leachy character and good underdrainage, it seldom contains much salt.

BINGHAM STONY LOAM.

This loam occurs above all canals, and constitutes a small area near the foothills of the Oquirrh Mountains, shown on the soil map by the brown color.   It consists of a thin layer of sandy or gravelly loam, underlaid by bowlders, rock, and conglomerate, which frequently outcrops, from a few inches to the height of a man, at the surface.   It is too stony for cultivation.

SALT LAKE SAND.

This sand is a product of Great Salt Lake, and consists of spherules about the size of No. 10 shot, which are made up almost wholly of carbonate of lime.   The accompanying table shows the mechanical analysis of a sample of this sand taken from the dunes along the lake shore.   It is known as oolitic sand, because it resembles the petrified eggs of fish.   Whether the spherules as such were formed in the process of separating from the water or whether they were formed by the action of the wind and water, from the broken fragments of lime-carbonate hardpan that occur in great quantity along the shore, was at first a matter of conjecture.

Mechanical analysis of Salt Lake sand.

Diameter.	Conventional name.	4355. Shores of G. S. L.
Millimeters.		
2 to 1	Fine gravel	0. 62
1 to 0.5	Coarse sand	2. 35
0.5 to .25	Medium sand	81. 25
.25 to .1	Fine sand	15. 32
.1 to .0001	Very fine sand—silt and clay	.51

Upon examining the different separations in the laboratory, however, it was found that the portion classed as fine gravel consisted of quite angular broken fragments of lime carbonate, the angles slightly rounded by erosion.   The particles of the next grade—coarse sand—were much more rounded, although the larger ones were still quite angular, as could be seen by the naked eye.   The third grade—medium sand— included over four-fifths of the sample, and in this all of the particles were well rounded, there being no angular ones.   Under the microscope the most of these particles proved to be almost perfect spheres, while a smaller proportion of them were oblong or egg shaped.   The

surfaces were quite smooth and highly polished. The fourth grade— fine sand—was similar to the third, but more of the particles were oblong and a few of them somewhat cylindrical, while the small percentage remaining in the class of very fine sand was chiefly angular particles of very fine sand and silt with just a trace of clay, the material being silice- ous, not carbonate of lime. All of the particles, except those of the very fine sand, when treated with dilute hydrochloric acid give rise to a vio- lent ebullition of carbon dioxid and soon disappear, leaving behind only a small flocculent precipitate, which, under the microscope, is shown to be clay particles with an occasional angular particle of silt. There seemed to be no nuclei to the lime carbonate particles, and all the evidence points to their formation by the breaking up of the thin pieces of lime-carbonate hardpan, which is quite abundant. These broken pieces, when sufficiently cubical, afterwards become rounded by the action of the water and the wind. Where the particles of lime-carbon- ate hardpan are flat they do not take on a rolling motion, and conse- quently do not become rounded. The particles are sufficiently soft to be easily crushed by pressure with a knife blade. It forms an insignifi- cant area along the shore, either as dunes, which in some places reach 10 or 12 feet in height, or spread out on the beach and on the slightly ele- vated areas near the lake shore as a layer of from a few inches to sev- eral feet in depth. Whatever its mode of formation, the material evi- dently comes from the lake water, which has reached the saturation point in regard to carbonate of lime.

HARDPAN.

The sketch map of the valley on page 103 shows a number of small areas of hardpan on the level lands between Salt Lake City and Great Salt Lake. This formation occurs over an aggregate area of about 12 square miles. The hardpan usually occurs under the Jordan sandy loam. This material is encountered at from 12 to 30 inches below the surface and at an average depth of 18 inches. It is from 2 to 18 inches thick, and averages about 3 or 4 inches.

The texture of the hardpan is the same as the material immediately above and below it, but this layer has been cemented by lime carbo- nate. Under ordinary conditions it is quite pervious to water and to the roots of plants, but when dry it is quite hard and difficult to dig. When moistened with water and soaked for a while it softens consider- ably, but does not disintegrate to any appreciable extent. It effer- vesces freely with hydrochloric acid and falls apart into a sandy loam.

As would be expected, the subsoil immediately below the hardpan is quite moist throughout the season, while above it the soil is quite dry during the summer months. The soil above the hardpan is usu- ally free from excessive quantities of alkali, while below the hardpan the salt content is very much greater.

On the shores of the Great Salt Lake very interesting observations

PLATE XIV.

FIRST STAGE OF THE FORMATION OF HARDPAN ON THE SHORES OF THE LAKE WITH DECOMPOSING ALGÆ BEING INCRUSTED WITH CARBONATE OF LIME.
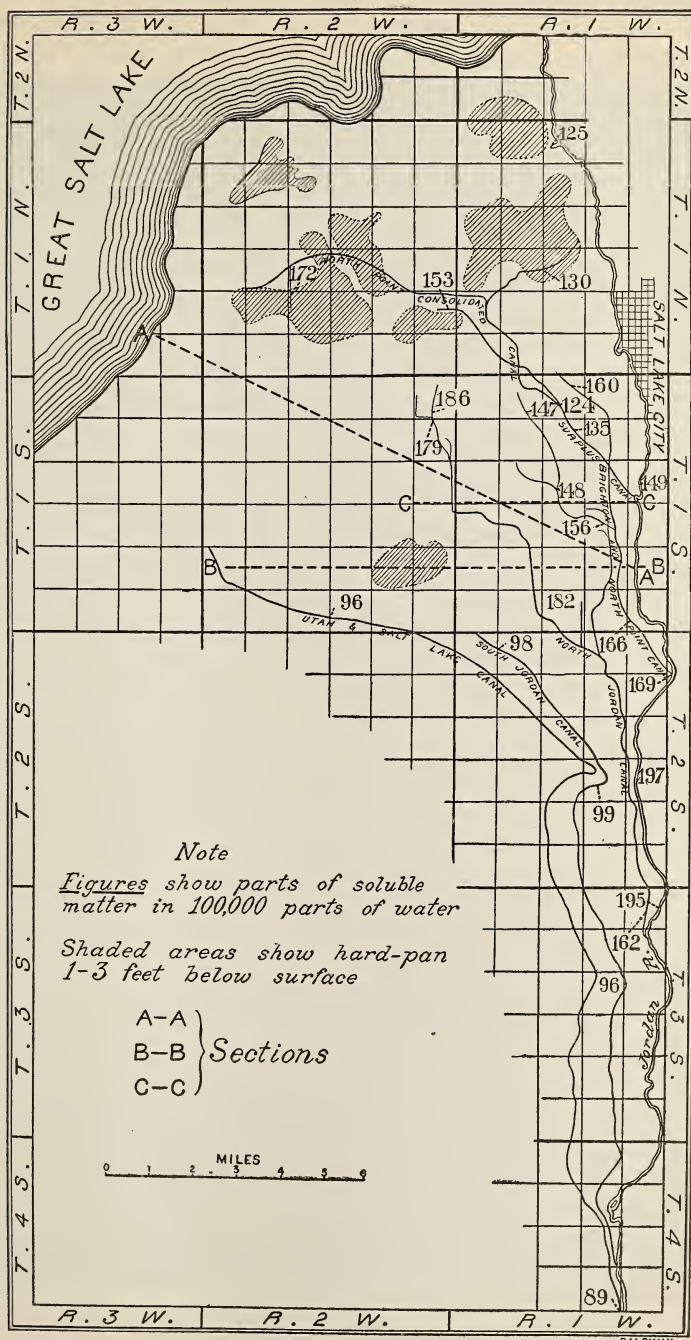
FIG. 10.—Sketch map of western part of Salt Lake Valley, showing canals, hardpan areas, and parts of salt in 100,000 parts of river and irrigation waters.

were made on hardpan forming on the surface and in all stages of formation. The preliminary stage was the washing up of algæ from the lake and of immense quantities of the salt shrimp, which lives in the lake waters, on to the beach. These gradually become crusted over with various salts, which, after repeated leaching, leave only the difficultly soluble lime carbonate. As the organic matter decomposes it is replaced with the lime carbonate, until the mass finally assumes the character of thin strata of broken limestone rock, nearly covering the surface over considerable areas.

Dr. Cameron has examined this material and has made the following interesting statements upon its probable mode of formation:

The samples collected on the shores of the lake by Mr. Gardner suggest some very interesting ideas as to the formation of hardpan. The samples all show the presence of calcium carbonate as such, more or less densely compacted, and there can be no doubt that this material is the cement holding together the other constituents which go to make up the hardpan. Calcium, in some form of combination, is present in the water of the Salt Lake. From an analysis made by Dr. J. E. Talmage in 1889 there appeared to be 0.084 per cent of calcium in the water, and it seems reasonable to suppose the amount is no less at the present time. The original source of the lime was probably in gypsum or carbonate of lime, and for our purpose it is a matter of indifference which it was. Gypsum (or the carbonate of lime either) is but slightly soluble in water free from other salts. But the presence of another salt markedly influences its solubility. If sodium chlorid be present, we shall have in the solution some sodium chlorid, some sodium ions, and some chlorin ions, thus:

$$\overset{+}{\text{Na}} \quad \overset{-}{\text{Cl}}$$
$$\text{NaCl}$$
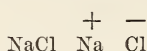
When the calcium sulphate is brought into contact with the solution we will get at once and in the same way calcium sulphate, calcium ions, and sulphions in the solution:

$$\overset{+}{\text{Ca}} \quad \overset{-}{\text{SO}_4}$$
$$\text{CaSO}_4$$
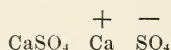
But the sodium ions and the sulphions present will unite to a certain extent to form sodium sulphate. At once there is a tendency for the sodium chlorid to furnish more sodium ions and the calcium sulphate to furnish more sulphions to restore the equilibrium. In the same manner the calcium ions and the chlorin ions will unite to form the very soluble calcium chlorid in the solution with a corresponding tendency to the formation of further calcium and chlorin ions. While the gypsum is but sparingly soluble, all these other salts formed are quite soluble, and more and more of the gypsum will dissociate and go into solution until equilibrium be reached. If the sodium-chlorid solution be at all concentrated, it has been shown that the amount of gypsum soluble in it is astonishingly large. In this way it is easy to see how lime salts could be carried down to the lake. But just as the presence of a salt increases the solubility of another without a common ion, it decreases the solubility of the second salt if they both yield a common ion. Of all the possible salts which may form in a solution when in instable equilibrium as regard saturation, that salt which is the least soluble will, of course, be precipitated. Thus it is that the waters of the Salt Lake containing large amounts of soluble sulphates, practically saturated with respect to them in fact, contain but a very small amount of calcium.

Moreover, the water of Salt Lake has been shown in this laboratory to contain a small amount of carbonate, either calcium carbonate or, much more likely, sodium carbonate. This fact is not recorded in any of the published analyses of the water, so far as I know, and as a matter of fact this need not cause any surprise under the

PLATE XV.
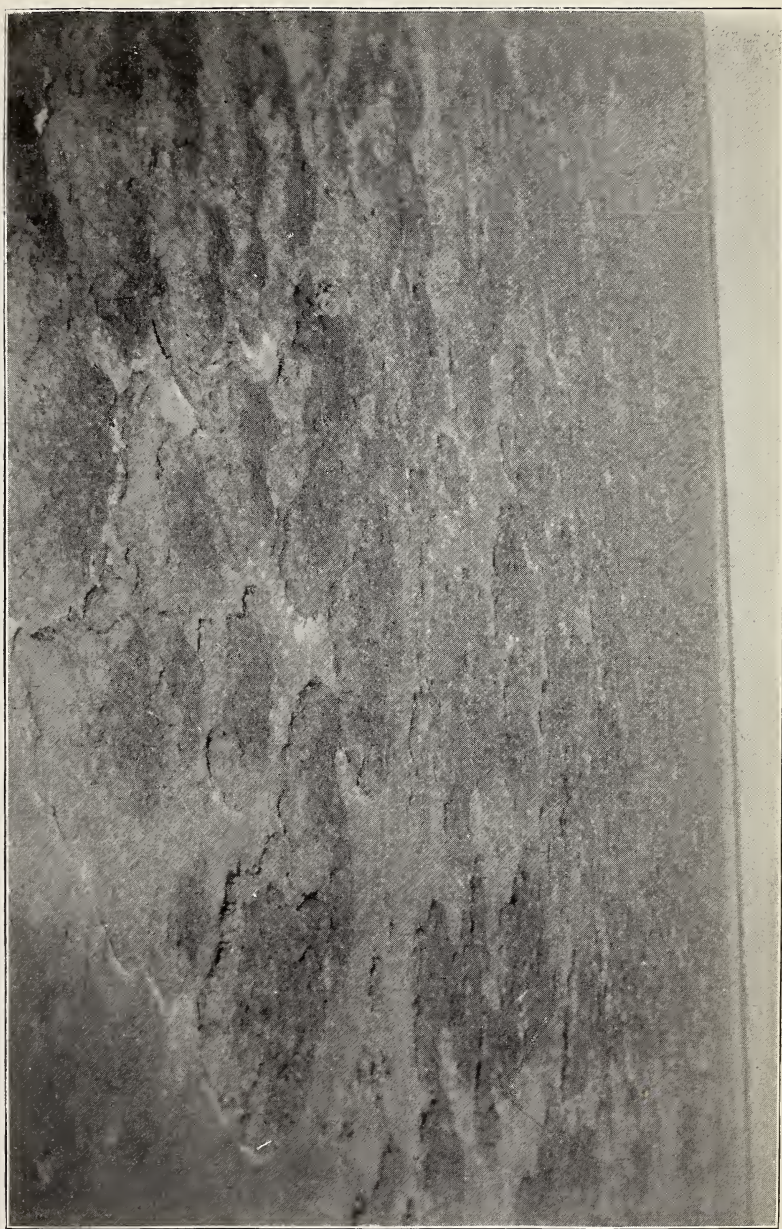
ADVANCED STAGE OF FORMATION OF HARDPAN ON SHORE OF LAKE.

circumstances. Its presence was discovered almost accidentally. Mr. Gardner had attempted to test the water for alkalinity by adding phenolphthalein solution. No color whatever was apparent, but on throwing the contents of the vessel away and attempting to rinse with distilled water a marked alkaline reaction was observed in the wash waters. Investigation showed the absence of any alkali in the distilled water. An examination in this laboratory brought out the explanation of the phenomena very clearly. There is sodium carbonate in the solution, and normally this would dissociate with the formation of sodium ions, which could be detected by the phenolphthalein. But the water contains so large an amount of salts with sodium ions that the solution is saturated with respect to this ion, and, carbonates being salts of a weak acid—that is, with a relatively small tendency to dissociate— the dissociation of the sodium carbonate is completely " driven back." Consequently there is no dissociated sodium carbonate in the solution. On the addition of more water, however, the concentration of the solution with respect to the sodium ion is decreased, more sodium ions may be formed, and the sodium carbonate dissociates, which fact is indicated by the phenolphthalein solution. This explanation was verified by repeated experiments with the water from the Salt Lake and with brines containing traces of sodium carbonate, prepared artificially. There is the further interest in these facts, that the absence of lime carbonates in the lake water has been the subject of much interest and speculation. The explanation is apparent from what has just been said. As the conditions are such that practically no disso- ciated calcium sulphate or dissociated calcium carbonate can exist, the water will only take up so much of these salts as is soluble without dissociation, somewhat less, in fact, than if the other salts were not present in the water.

At the edge of the lake the spray carrying various salts in solution falls on bunches of algæ and other organic matter, and, the water evaporating, the salts contained are precipitated. Theoretically the first to separate should be the small amount of calcium carbonate present, and in a general way this is probably so, but it is more or less mixed with the other salts. These other salts, being more soluble, are partially restored to the lake by the returning drip, by washing with rain water, etc., and the calcium carbonate already deposited will hasten the precipitation of more calcium carbonate from successive washings of spray, and thus it will gradually accumulate. In the specimens of the most recent formation collected by Mr. Gardner these views are well exemplified. In water, either cold or hot, the material is partially disintegrated and dissolved, fragments of the algæ (green and well preserved) being obtainable from the residue, as well as small twigs and other organic matter. The contents of the water solution appears to be in the main sodium chlorid, though other salts might be found on a careful examination. The solution showed the presence of but little lime and did not effervesce noticeably on the addition of an acid. The residue insoluble in water proved to be nearly entirely carbonate of lime, a very small residue being left after treatment with dilute hydrochloric acid.

Farther back from the water's edge specimens were obtained, consisting of twigs, grasses, etc., dead organic matter, bound together with a material which proved on examination to be nearly all calcium carbonate, though there appeared to be quite a small amount of sodium chlorid and other salts present. On treatment with dilute hydrochloric acid, besides the dead organic matter there was a small residue of fine sand or silt left. This hardpan, while much harder and more compact than the one first described, is still sufficiently friable to be broken with the fingers, though with some difficulty, and is fairly porous. It can be regarded as representing a subse- quent stage or later development of the first described specimens. The sodium chlorid and other water-soluble salts have been gradually washed out and returned to the lake. The calcium carbonate, by alternate redissolving and reprecipitation, has become more dense and compact. In this process the sodium chlorid may have been an important factor. It would seem quite probable that the dead organic mat- ter might play a decided rôle in yielding by oxidation carbonic acid. This carbonic

acid, in the presence of moisture, would dissolve the lime carbonate with the formation of the bicarbonate, and the bicarbonate, in turn, would reprecipitate as the carbonate on drying. Still farther back from the water's edge was found another type of material, evidently representing a later stage in the genesis of hardpan. This material appears to be but very slightly affected by treatment with water. It is practically all soluble in moderately dilute hydrochloric acid, a small residue of light brown silt remaining. The cementing material proves to be almost entirely lime carbonate with, perhaps, some magnesium carbonate. It is quite dense and compact and noticeably free from the undecomposed organic matter in the specimens last described. It evidently represents a later product of the process of resolution in carbonated water, reprecipitation on drying, and may fairly be taken as the type of the final product in the genesis of a lime carbonate hardpan.

On the shore between the two deposits last described (or still farther back in the form of wind-blown dunes) are found great quantities of small, remarkably well-rounded spherules, whose composition appears to be either entirely calcium carbonate or calcium carbonate about a very small nucleus of sand or some siliceous mineral. Several hypotheses have been suggested as to the origin of this material, but so far none seems to have received much credence. I am inclined to think they originated from the forming hardpan on the shore, by the action of waves during rough weather, by splitting up of the parent material by frost, the result of wind action, or of all these agencies. Their rounded form is quite easily accounted for in two ways—as the result of rolling from the action of the water; by the etching due to the solvent effect of the water, it being a well demonstrated fact that in the absence of any special reason to the contrary the result of such action is always to round off the edges and produce a spherulitic form, thereby reducing the surface, and consequently the "active mass," to a minimum. The striking uniformity in the size of the particles may be taken as confirmatory evidence of the views just presented. Suppose the particles to have been originally of widely varying masses. At such times as they would have been under the influence of the water they would have been stirring about in a heavy, rather viscous brine, whose specific gravity would not be very far from that of the carbonate particles. Naturally the heavier particles would gradually accumulate at the bottom, the lighter ones at the top, and, as the turbulent actions ceased because the particles had practically the same shape and density, those of equal mass would have equal volume and would settle at the same time. The larger particles at the bottom might well be expected to gradually consolidate if left undisturbed for sufficient time, and some specimens collected by Mr. Gardner indicate that such action has taken place.

WATER SUPPLY.

The main water supply for the western part of the Salt Lake Valley is derived directly from the Utah Lake and delivered through the Jordan River, the distance between the lake and the Jordan Narrows, where the later canals are taken out, being about 6 or 7 miles.

Utah Lake is a large body of fresh water, having approximately 125 square miles of surface, but rather shallow. It is fed by rather short mountain streams, derived largely from melting snow. The water in these streams is of excellent quality and quite free from salts. The water of the lake itself contains rather more alkali, as the seepage from the surrounding lands—both irrigated and nonirrigated—sensibly affects the salt content. In the spring of 1899 Mr. Means found the salt content of Utah Lake to be about 50 parts in 100,000. In a shallow lake with such an extensive surface area the effect of evaporation during the summer must sensibly increase the concentration of the salts in the

water. This probably accounts for the difference of the salt content of the lake, as observed by Mr. Means in July, and the 89 parts per 100,000 at the Narrows in the Jordan River, observed about the 1st of October by the writers.

There are seven canals taken out of the Jordan River between the Jordan Narrows and Salt Lake City for irrigation purposes, besides three or four small canals for water power. Five of the irrigating canals are on the west side of the river, but only three of these are at present used to any considerable extent for irrigating purposes.

The total flow of water in the Jordan River at the Narrows has been variously estimated at different periods between 1895 and 1899 at from 244.2 second-feet to 526.3 second-feet, the information being obtained from the office of the city engineer.

The North Jordan Canal was the first one of the great canals constructed on the west side of the river. It is taken out of the river about 9 miles below the Jordan Narrows. McAllister made a number of measurements in 1895–1897, inclusive, and found the flow in the canal to vary from 50.3 to 103.7 second-feet. This canal is about 14 miles long.

The next canal constructed on the west side of the river was the South Jordan, which is taken out of the Narrows, and is about 16 miles long. Various measurements have been made by a number of observers from 1895 to 1899 of the flow in this canal, and the results vary from 40.4 to 166.6 second-feet, with an average flow of about 75 or 80 second-feet.

The Utah and Salt Lake Canal, which is about 50 feet above the last-named canal, is also taken out of the river at the Narrows and is about 23 miles long. The measurements in this canal at different times and by different observers vary from 49.8 to 185 second-feet, with an average of considerably more than 100 second-feet. A considerable part of this, however, amounting at times to 50 per cent, is used by the power plant which supplies an electric current to Bingham and Mercer and returns the water directly to the river.

Observations made in 1899 show an estimated flow on June 4 for all canals taken out of the Jordan River of 526.3 second-feet; on August 18 of 325.6 second-feet; and on September 22 of 325.8 second-feet.

Besides the three principal canals used for irrigation on the west side, there are two others, namely, the Brighton and North Point and the North Point Consolidated, which were intended for irrigating the low land west of Salt Lake City, but which are hardly used at all at the present time. The North Point Consolidated Canal has a capacity of about 100 second-feet; the Brighton and North Point Canal is much smaller. There was enough water flowing past the intake of these canals during the summer of 1899 to have supplied their full capacity.

An analysis was made by Dr. Cameron of the solid matter of a sample of water from the Jordan River near the Narrows and of another

sample taken from the Jordan River opposite Salt Lake City. The following table gives the result of these analyses:

Kind and amount of salt in Jordan River water as determined by Dr. Cameron.

Kind of salt.	At intake of Utah and Salt Lake Canal, October 2.		At Salt Lake City, October 30.	
	Parts of salt in 100,000 parts of water.	Per cent of total salts present.	Parts of salt in 100,000 parts of water.	Per cent of total salts present.
Na$_2$CO$_3$	4.2	4.71	Trace.	....
CaSO$_4$	23	25.78	38	34.86
Na$_2$SO$_4$	11	12.33	9.8	8.99
MgCl$_2$	5.4	6.06	5.4	4.96
NaCl	45.6	51.12	55.8	51.19
Total	89.2	100	109	100
Residue dried at 105° C	98	....	118.4	....
Water of crystallization by difference	8.8	....	9.4	....

The sketch map of the valley (page 103) gives the total salt content in parts per 100,000 as observed during the progress of the survey in different parts of the valley. It will be observed that there is considerable fluctuation in the salt content of the river between the Narrows and Salt Lake City. This is dependent on two causes. On the east side of the river there are a number of mountain streams which deliver a considerable volume of snow water to the Jordan River, thus improving the quality of the water by dilution. On the other hand, there is a large amount of seepage waters collected by the river from the lands on either side, and, as these waters are generally highly charged with alkali salts, the salt content of the river tends to increase. Without this explanation of the conditions prevailing it would seem strange to see a salt content at the Narrows of 89 parts per 100,000 and this increased, at a point about half way to Salt Lake City, to 197 parts; at the intake of the surplus canal it is 149 parts, while at a point only two or three miles from the mouth of the river the salt content is 126 parts per 100,000.

The increase below the Narrows is to be ascribed entirely to the seepage from the adjoining irrigated lands on either side, while the comparatively low salt content near the mouth is due to the large volume of purer mountain water delivered by the several creeks which empty into the Jordan River at Salt Lake City.

The sketch map shows the salt content of the water in the irrigation canals so far as observed during the course of the survey. These measurements cover a period of four months.

For plants growing with their roots immersed in water, i. e., grown by water culture and not in the soil, the limit of endurance is about 1 per cent, or 1,000 parts of salt per 100,000 parts of water. A soil containing 0.4 per cent of salt, saturated with pure distilled water, would have in the soil moisture a concentration of 1 per cent. As all of these soils contain more or less alkali, and as evaporation and consequent

PLATE XVI.

NORTH POINT AND CONSOLIDATED CANAL SHOWING SEEPAGE ALONG SIDES OF CANAL.

Great damage has resulted to adjoining lands from the improper construction of canals. This is the source of the greatest injury to the lands in the valley.

concentration set in immediately after the application of water to the land, it is unsafe to use water having a concentration greater than about 250 or 300 parts per 100,000 for irrigating the lands.

According to this standard it will be seen that all of the canals deliver water of a good quality for irrigation purposes, especially the higher canals. The Utah and Salt Lake Canal contains only about 95 parts of salt per 100,000 parts of water, the South Jordan Canal contains hardly more than this, while the North Jordan Canal contains nearly twice as much, but is still well within the limit of safety, at least so far as immediate effects are concerned. The limit of safety is dependent upon so many things—such as the salt content of the soil, the texture of the soil, the drainage, kind of crop, the stage and condition of cultivation, and the climatic conditions—that only very general figures can be given for such broad application.

APPLICATION OF WATER.

The three principal canals on the west side of the river with which we have to deal are the joint property of the owners of the irrigated land, each man having shares in proportion to the amount of land owned. Anyone not holding shares can rent water rights from those who own more shares than they have personal need of. The water is generally apportioned among the landowners in proportion to the stock they control. The exact amount of water used per acre in this district has not been determined; but the average for the State of Utah is estimated at about 1 second-foot for each 100 acres. There is generally an abundance of water in the canal; but when there is any deficiency all suffer alike in a reduced supply. The water is allowed to run continually throughout the season and the excess runs onto uncultivated or pasture land. There is believed to be more water used at times of abundant flow than is absolutely necessary. Furthermore, the highland canals run for a portion of the distance through very pervious gravelly loams. The seepage and waste waters from the canals account in great measure for the 10 square miles of good land which has already been ruined by seepage and alkali. It has been shown that the water is of good quality and the lands of the upper benches are naturally free from any great excess of alkali; but the continual seepage from the canals during the growing season for a great many years has transported a quantity of salt to the lower levels.

The necessity of careful construction of the canals, especially those on gravelly lands, and the desirability of preventing the waste water from flowing over the lower levels is sufficiently obvious without further comment.

The application of water on the low lands west of Salt Lake City, where there is a large amount of alkali in the lower depth, has been attended with very disastrous results to crops. The salt has quickly

risen to the surface and, even where the surface foot was originally free from alkali, the crops have been completely ruined in the course of two or three years.

A very serious feature of the prevailing practice is that the land upon which an excess of water is used, or the land adjacent to a leaking ditch, is often not injured for a while and may even be improved by the excess of seepage water; while the lands at the lower levels, perhaps under the second or third ditch, may receive the full effect of this pernicious practice or condition.

The advisability and even necessity of State legislation, to compel the ditch owners to guard against undue seepage and to prevent the property owners from using excessive amounts of water in irrigation, is sufficiently obvious to require no further comment at this place. Property owners whose lands are damaged by either of these means should be able to recover damages in civil suits.

UNDERGROUND WATER.

One of the maps accompanying this report gives the depth to standing water at the time of the survey. One of the three shades of green shows the area upon which standing water is found within 3 feet of the surface of the ground; another shows the area where the water is between 3 and 10 feet of the surface, and the third color shows where it is below 10 feet.

With standing water within 3 feet of the surface of the soil it is in no condition for any of our agricultural crops. Such areas must be drained in order to use the land for agricultural purposes. With water within 3 to 10 feet of the surface there is always more or less danger in the application of irrigation water. It is incumbent upon the owers of such land to watch the fluctuation of the underground water and to underdrain wherever necessary.

The texture of the soil, and especially the character of the subsoil, will largely determine the extent of the danger to be feared. The large areas south of Salt Lake City and the areas along the Jordan River with standing water within 3 feet of the surface are believed to be due entirely to seepage from the canals and from the irrigated lands above.

The underground water map shows, therefore, the areas which require immediate drainage to relieve the soil of surplus water. It is incumbent upon all those living within the areas colored medium and dark green to provide adequate drainage when the danger from underground water becomes imminent.

One of the pernicious effects of the accumulation of seepage waters is that the soil is made closer and more difficult to drain, therefore artificial drainage can be more economically and effectively applied before, rather than after, the collection of seepage waters near the surface.
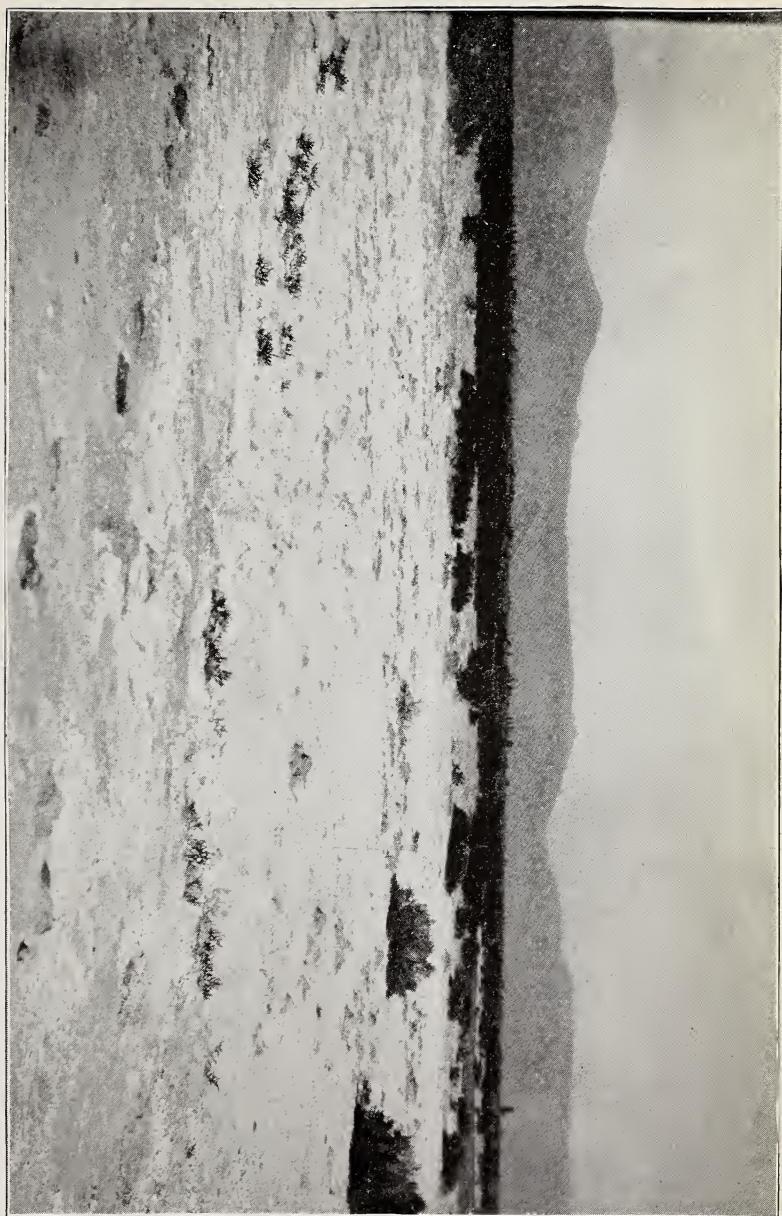
PLATE XVII.

LAST STAGE OF VEGETATION WITH ACCUMULATION OF ALKALI.

The last stage of vegetation is small annual saltbushes.

PLATE XVIII.

ALKALI FLAT—TOO STRONG FOR SALTBUSHES.

Even saltbushes will not grow where the salt content in the top 6 feet of soil approaches 3 per cent.

PLATE XIX.

ALKALI FLAT, FINAL STAGE, WITH NO VEGETATION.

These are indeed barren.

ALKALI IN SOILS.

The following table gives the composition of the alkali in the soils and crusts from a number of localities, as determined by Dr. Cameron. It will be seen that the sodium chlorid constitutes from 50 to 97 per cent of the total salts. The next largest constituent is sodium sulphate. The calcium sulphate is a difficultly soluble salt, and when the water evaporates this will be deposited in the soil as harmless gypsum which will not readily go into solution again. The other salts are all quite soluble and are liable to accumulate and concentrate in the soil mois-ture upon evaporation of the water from the surface of the land.

Chemical composition of salts in crusts and soils as analyzed by Dr. Cameron.

No.	Locality.	Na_2CO_3.	$CaCl_2$.	$MgCl_2$.	$CaSO_4$.	$MgSO_4$.	Na_2SO_4.	NaCl.
4366	S. 1, T. 1 S., R. 1 W	....	0.77	0.38	1.98	....	....	96.90
4381	3 miles northwest of S. L. C..........	0.96	....	....	.79	0.25	31.15	66.84
4382	S. 32, T. 1 N., R. 1 W	9.28	....	....	1.06	.37	43.12	46.17
4383	S. 14, T. 3 S., R. 1 W	....	....	10.41	13.24	3.16	....	73.18
4384	S. 24, T. 1 S., R. 2 W	Trace.	....	....	2.14	.12	11.97	85.94
4385	S. 2, T. 1 S., R. 1 W	Trace.	....	....	6.38	29.87	8.29	55.48
4386	S. 16, T. 1 S., R. 3 W	Trace.	....	6.21	3.72	.75	....	89.31
4387	S. 29, T. 1 S., R. 1 W	.23	....	....	7.43	22.61	9.75	59.98
4388	Chambers, 2 miles east	....	7.62	10.37	9.97	....	....	72.04
4389	S. 4, T. 1 S., R. 1 W	.30	....	....	.25	.71	49.43	49.30
4390	S. 1, T. 1 S., R. 2 W	....	....	4.77	9.32	2.64	....	83.26
4391	S. 14, T. 3 S., R. 1 W	Trace.	....	....	7.33	32.32	9.86	54.49

The amount of alkali was determined by the electrical method in every foot down to at least 6 feet in depth. The alkali map represents what may be considered the average conditions, according to the judg-ment of the observer. If a boring showed a small amount of alkali in the surface foot and a large amount in the remaining depth the soil was classed as unfit for cultivation, as it would require but one or two applications of water to bring an excessive amount of salt to the surface.

Attention is called to the very large accumulation (over 3 per cent) of soluble salt in certain areas in the land west of Salt Lake City. There is a general agreement between the alkali map and the soil map, as would be expected, but this is influenced to a considerable extent by the topography of the country. The heavy clay soils and the land having this material within a short distance of the surface have gen-erally the largest accumulation of alkali, on account of the imperfect drainage. The soil of the uplands is naturally free from excessive amounts of alkali, while the level area between Salt Lake City and the Great Salt Lake contains excessive amounts of salt. This latter fact is undoubtedly due to the influence of the Great Salt Lake, which, within comparatively recent years, covered much of this area. There are no antidotes for this kind of alkali, with the exception of the sodium car-bonate, and adequate artificial drainage is the only practical means of reclaiming the land and providing against further disaster. The pos-sibilities of reclaiming the level tract west of Salt Lake City will be described under a subsequent head.

One interesting fact brought out in this investigation is that alfalfa appears to stand a slightly higher salt content in the Salt Lake Valley than either in the Yellowstone Valley of Montana or the Pecos Valley of New Mexico. This may be due to the longer period in which agriculture has been practiced in this locality and the gradual adaptation of the alfalfa to these alkali lands. This is a matter which requires fuller investigation by the Vegetable Physiologist.

It is clearly apparent, from the investigations in the Salt Lake Valley, that our different staple crops can stand different amounts of alkali. These limits have been shown on the alkali map by different colors.

A number of factors enter into the question of the limit of endurance of plants for alkali. With the same amount of alkali plants will suffer less in the heavier soils than in the sandy. They will stand more alkali with thorough cultivation, and they will often stand a considerable amount of alkali if they are started under favorable conditions. In some districts of California sugar beets do well on soils containing a large amount of alkali. They are planted in the spring when the ground is wet either by rains or by previous irrigations, which carry the alkali into depths of the soil. When the soil dries out the alkali is brought to the surface and is left above the area of the active roots. It is a common practice in some localities to irrigate heavily just before planting in order to accomplish this very purpose. Obviously this method would not be successful when the soil to a considerable depth contains an excessive amount of salt.

Along the ridges and draws in the level west of Salt Lake City, where good drainage is secured, crops are frequently cultivated with a moderate degree of success when the land has a salt content higher than would be permissible were the drainage less complete. In a considerable percentage of this area the surface is comparatively free from alkali. Many attempts have been made to bring such land under irrigation, but the results have been disastrous after one or two years. In the upland soils of this locality the excessive accumulation of alkali, in land which was formerly free from salt, is almost invariably preceded by an accumulation of seepage water. The treatment for alkali, therefore, in soils previously free from salt, is almost always accompanied by the problem of getting rid of the seepage waters.

BLACK ALKALI.

The corrosive sodium carbonate is present in considerable amounts in the soils west of Salt Lake City. The best antidote for this, as Hilgard has pointed out, is the application of calcium sulphate, which, under proper conditions of drainage and aeration, converts the sodium carbonate into sodium sulphate or white alkali. On every area in which there is an excess of sodium carbonate there is also an excess of white alkali. It would be a waste of money, therefore, to apply calcium
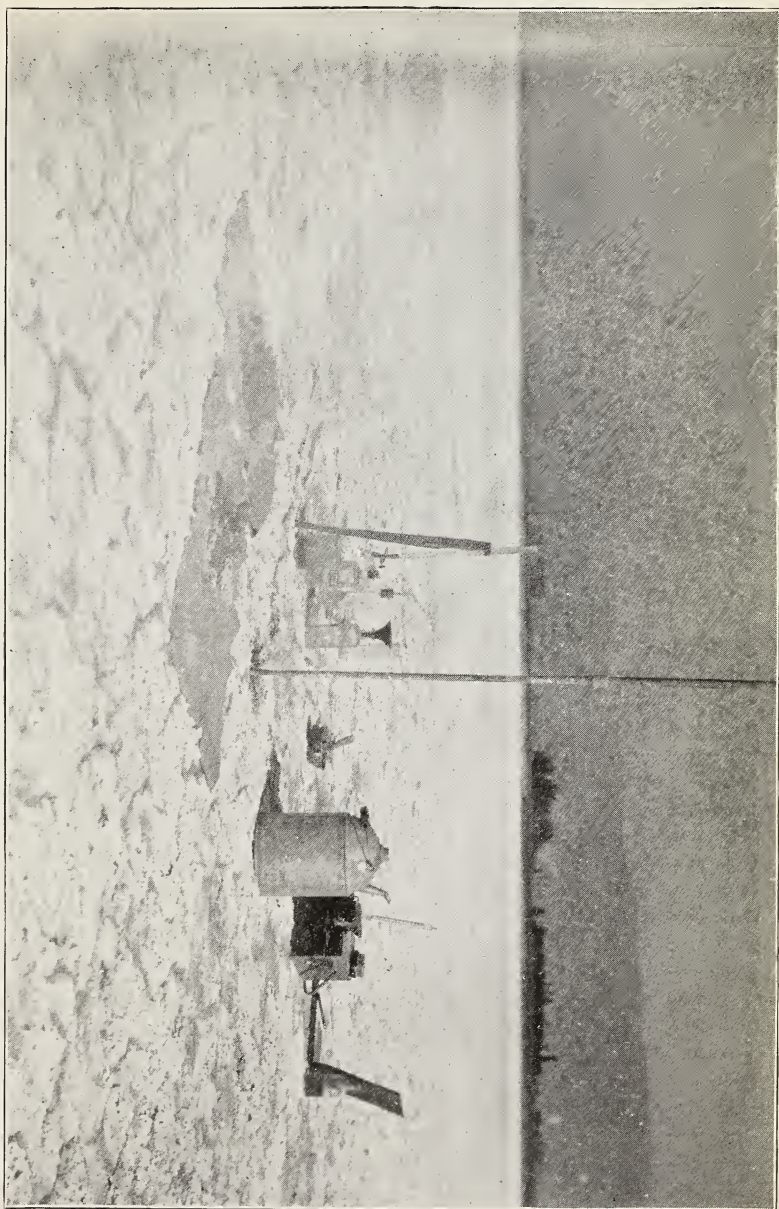
INSTRUMENTS FOR SALT DETERMINATION ON RIGHT OF AUGER, AND FOR SODIUM CARBONATE AND CHLORID ON LEFT OF AUGER.

Small and convenient outfit for determining the soil conditions.

sulphate, as the sodium carbonate would be washed out along with the white alkali on the introduction of proper drainage and flooding.

The limit of endurance of plants for sodium carbonate is assumed to be that which Hilgard determines for the California soils, namely, 0.1 per cent. The lower limit of what may be called the danger line has been placed at one-half this amount.

Attention is called to the very large amount (over 0.25 per cent) of sodium carbonate in the soils of certain areas. The surface crusts occasionally contain as much as 10 per cent of sodium carbonate. Quite often there are large accumulations of calcium chlorid, which in one instance has amounted to about 40 per cent of the total salts present. There is also frequently an appreciable amount of strontium chlorid in the crust, and the suggestion is made that some of the deposits may be sufficiently rich in one or more of these three salts to warrant commercial development. No special attention, however, was paid to this particular feature.

UNDERDRAINAGE AND THE RECLAMATION OF WASTE LAND.

Attention has already been called to the necessity of underdrainage for protection against injury from seepage waters and alkali and for the reclamation of injured lands. Irrigated lands in the Salt Lake Valley are worth at least from $60 to $100 per acre. Lands immediately adjacent to Salt Lake City, especially if held as suburban property and if free from alkali, would be worth much more than this. There is plenty of good tile clay in the vicinity of Salt Lake City, and tile could be manufactured for the farmer at a reasonable cost. It is estimated that it would cost from $10 to $20 an acre to underdrain these lands which, under the present conditions, have a merely nominal value.

Lands in New York, Ohio, and Illinois, worth from $50 to $75 per acre, have been very extensively underdrained in order to increase their productiveness, to hasten the maturity of the crops, and to insure the crops from injury by drought. It would certainly be a reasonable proposition to protect these valuable lands and to reclaim in the same way what would be valuable land. Money so invested is in the nature of an insurance against loss of crops from seepage waters and alkali.

During the course of this investigation particular attention was given to the possibility of reclaiming the vast tract of 125 square miles between Salt Lake City and the Great Salt Lake. The levels of the railroad surveys and of the canal companies were freely consulted. At Salt Lake City the level of the Jordan River is about 20 feet above the level of the water in the Great Salt Lake. The distance across is about 14 miles. There is a slight ridge, however, running a little west of north, about a third of the way across from Salt Lake City. From the crest of this ridge to the Great Salt Lake there is a uniform fall of approximately 3 feet to the mile. This would be ample for the main

drainage canals, as the irrigating canals have only about one half this fall. Furthermore, there are many draws, already 4 to 8 feet deep, extending like fingers through this area, which with little additional work could be made to answer for a considerable part of the drainage system.

On account of the impervious nature of the Jordan clay, the great salt content, and the low elevation, it would not be advisable to attempt drainage over this class of land at the present time. Subtracting this area, estimated at 35 square miles, from the 125 square miles, the value of the remaining lands, if thoroughly drained, would be about $3,000,-000. At present they have merely a nominal value.

Any large drainage system of this kind can be established more efficiently and economically by a company than by individual effort. For an enterprise of such magnitude—so nearly affecting the welfare of a large number of people—the State or county could well use its credit in assisting the undertaking. This is commonly done in similar enterprises in other localities. There seems to be little doubt of the feasibility of reclaiming this land from the engineering point of view and, with the abundant supply of water, there is still less doubt of the efficiency of the system when once introduced. The possibilities should appeal to the commercial spirit of the people and induce capital to undertake this very desirable enterprise.

ACKNOWLEDGMENT.

A RECONNOISSANCE IN SANPETE, CACHE, AND UTAH COUNTIES, UTAH.

By THOS. H. MEANS.

GEOGRAPHY AND TOPOGRAPHY.

A portion of July, 1899, was spent in a rapid survey of the alkali soils of Utah, Sanpete, and Cache counties in Utah, with the following results, briefly given. The conditions in these three districts are in general very similar, yet each district differs from the others in certain respects.

Utah County lies directly around the fresh-water lake that bears the same name, and all of its irrigated land is on what was, at a previous epoch, the bed of Lake Bonneville. The soils are the sediments of this ancient lake, more recently modified by the inflowing streams and by weathering.

The irrigation water supply is obtained from the mountain streams, the principal ones being American Fork, Provo River, and Spanish Fork. The source of the water supply for these streams, during the irrigation season, is chiefly the melting snow on the high mountains of the Wasatch Range, and the water is therefore of excellent quality. It contains about 15 parts of soluble matter per 100,000.

The irrigation systems consist of a series of canals and ditches owned and operated by the farmers. Parts of the valley have been under cultivation for about forty years. When the valley was first settled the strip of land immediately around Utah Lake was wet and swampy. By irrigating the upland the wet land has greatly increased in area, this increased wet area becoming less valuable, although still furnishing desirable grazing. The principal damage is from seepage waters, but where the soil is heavy, salts have accumulated at the surface in sufficient quantities to seriously damage the meadows.

Moderate amounts of salts are everywhere present in the soil and through the agency of irrigation and seepage waters they are concentrated within small areas. An examination of the seepage waters from the benches showed comparatively small amounts of salts present, but these mildly charged solutions are often much concentrated by evaporation and give rise to large accumulations of salts in the soil.

Sanpete County is located in the central part of Utah and its farming lands lie in the valleys of the San Pitch and Sevier Rivers. The land lies at a greater altitude than the ancient Lake Bonneville, and the soil formation is therefore somewhat different from that of the preceding county. The valleys are more level and slope more gradually to the mountains than in the lake basin proper.

The irrigation water supply is derived from several sources. Around and above Manti the water is taken directly from the mountain canyons and is good. Ten miles above Gunnison the San Pitch is dammed, thus forming a storage reservoir which supplies water farther down the valley, around the junction of the San Pitch and the Sevier.

The water of this reservoir, at the time it was examined, carried between 50 and 100 parts of soluble matter per 100,000. The lands to the south of Gunnison receive their water supply from the Sevier River, as do also the lands around Richfield. The water of the Sevier River during a part of the year is diverted at a point above Gunnison. Gradually a portion of it returns to the river as seepage and at Fayette it is again all taken out for irrigation. Still farther down, at Deseret, the stream is drained for the third time.

The water as first taken from the river is good; but the second time it is contaminated by the seepage from the Gunnison district. The water in the Fayette Canal contained, in July, 1894, 250 parts of soluble matter per 100,000; while in the Sevier River, just below Fayette, it contained over 300 parts. At Deseret it was probably still worse. The application of water containing more than 300 parts of soluble matter per 100,000 is attended with great risk unless precautions are taken to prevent concentration within the soil.

Cache County lies in the north-central part of Utah, the farming lands receiving water directly from the tributaries of the Bear River. The irrigation water supply is taken from the mountain streams and is of excellent quality.

SOILS.

The soils of the three districts mentioned above are so similar that they may be conveniently discussed under one head. The farming lands of both Cache and Utah counties are all in the Bonneville beds, and the soils were formed from sediments deposited from the ancient lake, and have, since its subsidence, been considerably modified by inflowing streams and by weathering. The soils of Sanpete County lie above the level of the ancient lake and were formed by material brought down from the adjacent mountains. They are very similar, however, to those of the two preceding counties.

In each of the districts the soils in several parts vary from light sand and small gravel, through all grades, to the heaviest and most tenacious clays. The upper benches of the deltas around the mouths of the canyons, and also the shore benches of Lake Bonneville, are covered with gravelly soils, grading down into coarse gravel. These soils are

well underdrained and therefore free from salts, but owing to the thinness of the soil proper, and to the difficulty of applying water and cultivating the soil, they are but little farmed. The soils of the lower benches contain less gravel, but are sandy and of light texture.

Upon the lower and more level parts of these valleys there are great variations in the soils. In those parts farthest from the inflowing streams, where the water movement is slow, the soils are heavy and often contain as high as 50 per cent of clay. As we approach the entrance of streams, where the water movement becomes more and more rapid, the soils are noticeably lighter, grading through loam, sandy loam, and at the mouths of streams becoming sandy or gravelly. Irrigation on the loose soils results in the transportation of considerable salt to the lower and heavier soils, where it is most difficult to get rid of. Around Utah Lake there is considerable of this heavy land that has been more or less damaged by seepage and alkali from the lands above, and in Cache Valley there is a large area of wet clay land which is used for meadow and grazing. Though of considerable value in this way, the value could be much enhanced by drainage and cultivation.

ALKALI IN SOILS.

In Utah and Cache counties both the black and white forms of alkali are present. Originally moderate amounts of alkali were probably everywhere present in the soil, and through the agency of irrigation and seepage waters a part of these salts has been transported and concentrated in local spots.

The three following analyses, by Dr. Cameron, show the approximate composition of alkali from Utah County:

	4160. Crust from shore of Utah Lake.	4161. Black crust, 2 miles N.W. of Provo.	4162. White crust, 3 miles N.W. of Provo.
$CaSO_4$	3.96	....	....
$MgSO_4$	33.68	....	6.32
Na_2SO_4	10.02	....	65.73
$NaCl$	52.34	79.09	26.69
Na_2CO_3	0.00	20.91	1.26

The crust, No. 4160, was collected from near the shore of Utah Lake upon a bar surrounded by swamps. The water of the lake contains gypsum in solution. Gypsum acts as a chemical correction for the black alkali, changing it over into sodium sulphate. Here the process has been complete; all of the sodium carbonate has disappeared.

In sample No. 4162 the per cent of sodium carbonate is so small as not to show black in the crust as collected.

The black alkali, where present, is in spots and small areas and its reclamation with gypsum will prove an easy matter.

In Cache County the black alkali is limited to spots and tracts in the west-central part of the valley and is always associated with the white alkali. Gypsum is found in some of the heavier soils and serves a valuable office in ameliorating the severity of the black alkali.

The following analyses, by Dr. Cameron, show the composition of the salts under the two typical conditions:

	4172. Tule swamp crust, 5 miles SW. of Logan.	4174. Black crust, 3 miles SW. of Logan.
CaSO$_4$	2.07	....
MgSO$_4$	39.11	....
Na$_2$SO$_4$	36.38	46.38
NaCl	22.44	41.06
Na$_2$CO$_3$	....	12.56

In Sanpete County the alkali, so far as examined, was all white. The presence of gypsum in nearly all of the soils and in the irrigation waters would lead one to expect this.

The following analyses, by Dr. Cameron, illustrate the variation in the composition of the salts:

	4165. Red crust, 5 miles S. of Gunnison.	4166. White crust. 5 miles S. of Gunnison.	4170. Yellow crust from kaolin mine, 2 miles SE. of Gunnison.	4171. White crust under loose soil from hillside, 3 miles SE. of Gunnison.
CaSO$_4$	1.27	3.14	3	3.51
NaSO$_4$	73.40	89.03	....	95.60
MgSO$_4$	....	....	7.18	....
MgCl$_2$	....	....	4.47	....
NaCl	25.33	7.83	85.33	0.89

Samples 4165 and 4166 represent the alkali as found in the soil, while 4170 and 4171 were collected to represent some of the possible sources of the salts. In each of these samples gypsum is present in sufficient quantity to prevent the formation of black alkali in a well-aerated soil. In the foothills south of Gunnison rock salt is mined; the streams cutting through these hills are likely to become contaminated with this salt and carry it to the irrigated lands below, much to their detriment. No actual exposure of the salt is at present visible along the stream beds, but the underground flows and heavy floods, no doubt, carry much of this salt valleyward.

One of the highland canals, running along the base of these hills, leaked in a gravelly place and the resulting seepage at the foot of the hill was heavily charged with salt and formed a heavy crust over the surface of the ground. There is much apprehension that this upland canal, through its seepage, will wash alkali down to the lower, heavier lands and damage them. In order to prevent this the canal should be protected from leakage and great care exercised in the use of water on

the light soils of the upper slopes. Wherever the level of standing water begins to rise and threatens to come near the surface the land should be underdrained. Protection from seepage is sometimes afforded by a seepage ditch, providing the ditch is dug along an impervious layer which naturally rises, and therefore raises the seepage waters. If no such layer is present a seepage ditch would afford little protection.

Where irrigation waters carry a high percentage of salts, or where the soil is naturally salty, surface flooding is thought to be better than furrow irrigation. By furrow irrigation a crust of salt accumulates along the tops of the furrows to such an extent that in time it may prevent the growth of plants, except in the bottom of the furrows where the water washes down the accumulation of salt from the previous irrigation. By flooding, the salts over the entire surface are washed down and, if drainage be good, they will pass off through the underground drainage, but if the drainage be poor they will return to the surface. To prevent as far as possible the return of salts to the surface, the growth of shading crops or thorough surface cultivation should be resorted to.

There are some plants more resistant to alkali than others, and by the cultivation of these, alkali lands may be at times utilized. Such plants as the Australian saltbush, sugar beets, sorghum, and sweet clover are worthy of trial.

It is found that sweet clover will grow successfully with as much as 1 per cent of salt in the soil. It is a biennial, and therefore easily removed from the land. It is a deep-rooted legume, and consequently loosens the soil and supplies nitrogen. Its blossoms furnish excellent bee food and the leaves and stems are eaten by cattle to some extent. It serves the twofold purpose of improving the land and furnishing forage.

SUMMARY.

The discussion of the conditions in the three counties included in the reconnoissance shows, in all the cases cited, that the presence of alkali salts within the soils is due to defective natural drainage. The obvious remedy is artificial drainage. Where farming is as intensive as it is in some parts of Utah the first step in the natural reclamation of the land, after application of water, should be drainage. This feature of the irrigation question has been neglected and the result has been the damaging of valuable land. The method which should now be adopted for the reclamation of the lands abandoned on account of seepage waters and alkali is the same method which, if originally applied, would have insured against such damage—that is, underdrainage. Tile drains offer the most effective and, in the end, the cheapest method of draining the soil.

The application of gypsum or land plaster can be recommended for the black alkali soils. The effect of the gypsum on such soils is twofold: First, the gypsum improves the physical condition of these heavy lands, that is to say, it renders the soil more loamy in character and

easier to cultivate and drain; and, second, it neutralizes the black alkali, turning it into the white salt. Gypsum is not a chemical anti-dote for the white alkali, and its application to white alkali lands can be of little value, except in so far as the gypsum improves the physical properties of the soil.

The growth of deep-rooted crops tends to loosen the soil and to per-mit the free downward movement of the water. This effect, together with the shading of the ground in order to prevent evaporation and the consequent formation of alkali, is well illustrated in the growth of alfalfa.

A RECONNOISSANCE IN THE CACHE A LA POUDRE VALLEY, COLORADO.

By THOS. H. MEANS.

SOILS AND ALKALI.

The Cache a la Poudre Valley, or the Greeley country, as it is some-times called, is one of the oldest as it is one of the most prosperous irrigation districts of the West.

One month was spent in a reconnoissance of this valley in the summer of 1899, and as the conditions there are unique in a way the results of the investigations may be of more than mere local interest.

The Cache a la Poudre Valley, or at least that part of it which lies east of the foothills of the Rocky Mountains, is cut from a series of nearly horizontal strata of cretaceous rocks. That portion of these strata which is exposed in the irrigated parts of the valley is largely sandstone or sandy shale, though at some places a bed of heavy blue shale is exposed. From these shales and sandstones the soils of the valley are formed, modified in a measure by the mixture of materials brought down from the mountains by the streams. The farming lands are situated on a more or less perfect system of terraces extending back from the stream and merging indefinitely into the upland, which consists of hills rounded by erosion. The lateral valleys, which extend back from the main Poudre Valley, are the result of flood erosion, no water flowing through any of them before irrigation was practiced except during times of heavy rains.

The soils of the bottom lands are generally sandy or gravelly, with coarse, gravelly subsoils. Such soils, where well drained, furnish excellent truck lands; but the greater part of this low land is wet from the seepage from the upper irrigated lands, and at present is used for pasturage and hay crops.

The second and third bottoms consist of heavier soils, becoming in some places a heavy clay. This clay land, on account of its impervious nature, acts as an obstruction to the flow of seepage waters from the uplands, and is in consequence often wet or alkaline. This type of land abuts directly against the upland soils, and extends around the mouths of the draws and lateral valleys. The same type

of heavy soil is found in the bottoms of the draws, where the natural moisture has collected the fine particles of soil from the hillsides and promoted the disintegration of the large grains.

The greater part of the farming lands of the valley lies upon the rounded hills of the uplands. The soil on these hills is a sandy loam in nearly all cases, varying slightly in texture. Immediately north of Greeley it contains about 7 per cent of clay, while north of New Windsor it contains 12 per cent, and around Fort Collins the soils are as a rule still heavier.

Many inclosed basins are found throughout the country, in the bottoms of which the soil is heavy and impervious. In these natural basins the water collects after each rain, and when they are irrigated the waste water collects in the lowest parts, forming swamps. The bottom lands were the first to be irrigated, and as the country became more thickly settled new canals were built covering the higher lands. In this way the irrigated land has extended back from the river to a distance in some places of more than 10 miles. The construction of one canal above another in this way has opened a wide field for inquiry into the possibilities of damage from seepage water, and in the present investigation special attention was given to the damage already done and to the possible remedies for this damage.

Since the time allotted to the field work was too short to warrant a complete study of the district, two townships were selected, comprising a strip of land from the Poudre to the desert land above the uppermost canal, the Larimer County Canal. This section was studied in detail, and the areas of wet or alkali soil were outlined in the field on a map. In this way a definite idea was obtained of the amount of wet land which at present exists, and the best means for removing this excess of water were considered.

It was found that the amount of wet land under the Larimer County Canal is small and confined to the bottoms of draws and land immediately adjoining the canal. The whole of the area under the Larimer County Canal is not farmed at present, but when all the land is farmed this area of wet land will be likely to increase. The seepage water, however, seems to originate in the losses from the canals and constantly running laterals rather than in seepage from the irrigated fields.

Professor Carpenter, of the Colorado Experiment Station, has investigated the question of the origin of the seepage waters, and, in his opinion, the greater part comes from the canals and laterals.

The material through which the canals run is largely loose in character, and the water is clear, carrying very little material which would clog the interstitial spaces of the soil. There can be no question, however, but that over irrigation, through ignorance or neglect, is also the cause of much seepage. The effect of over irrigation is very noticeable in some districts, and the careless use of water can not be too strongly condemned. It not only injures the land to which it is applied, but it

also largely increases the seepage water to the destruction of lower lands.

Under the Larimer and Weld Canal the amount of actual damage is greater than under the Larimer County Canal. The lands have been under irrigation longer and the subsoil has had more opportunity to fill up; besides, the amount of land irrigated is larger. This land also receives the seepage from the lands under the Larimer County Canal.

Under No. 2 canal the amount of wet land is still larger than under either of the canals above mentioned. It receives the seepage from all the land above, as well as the seepage from several reservoirs situated at a higher elevation. The soils under No. 2 canal are heavier than the upland soils, the land is more level, and the natural drainage is poorer. In the district mapped several large areas of wet land under this canal are shown. This area receives the direct seepage from all the upland, and since the underlying beds of gravel are not contiguous to give adequate drainage, the water tends to rise to the surface in places and swamps are formed.

One of the first questions which should be considered in the opening of new farming lands is the drainage. If the natural drainage is good— that is, if the excess of water is quickly removed from the subsoil—the installation of drains is not necessary, but if the water at any time stands within the subsoil or if the excess of water, applied through irrigation or falling as rain, does not quickly pass away through the underground drainage the crops grown upon the land will suffer and the farmer will not obtain the best results from his efforts. The wet land of an irrigated country should be immediately drained when the level of water rises closer than within 3 feet of the surface of the ground. It may be that the water rises near the surface only during a limited period of the year, but this may be long enough to injure a crop.

The underground waters of an irrigated district situated within the arid regions of the West are never free from salts in solution. When this water is allowed to approach the surface of the ground it evaporates, leaving its burden of salt on or near the surface. The salt continues to accumulate in this manner unless the surface water is drained away. Usually such a quantity of salt accumulates that nothing useful will grow upon the land. When reclamation is attempted both the water and salt have to be removed, thus making the work of reclamation very difficult and costly. From the standpoint of economy, therefore, it is much better to install drains before or at least as soon as the ground becomes wet. This will not only remove the excess of water, but will insure the land against ever becoming alkaline.

In the Greeley district the process has as yet gone in most places only far enough to damage the ground from water. If the water is not removed much more damage is probable from alkali. A wet piece of ground is valuable in some cases as pasture, but a piece of badly alkaline land is practically worthless. The underground waters are not

highly charged with salts and the evolution of an alkali flat is slow, but none the less sure. In the shales of the underlying rocks quantities of alkali are stored, and where the seepage water passes through this shale and appears again the accumulation of alkali at the surface is much more rapid.

Repeated tests were made for sodium carbonate, but none was found. This was to be expected, since all of the soils contain small quantities of gypsum, which is the chemical antidote for black alkali.

There is no chemical preparation known which would render the alkali of the Poudre Valley harmless, consequently in order to redeem the lands already damaged these salts must be removed from the soils and removed so far that there can be no possibility of their ever coming back again. There is but one known way of effectively removing these alkali salts, and that is by underdrainage. In the Poudre Valley at present only the lower lands are in need of drainage. The lower lands along the Poudre River and the immediate bottoms of the draws extending back into the hills should be drained at once. In some cases a simple line of drains up the center of the draw would suffice for the present and would insure much of the bottom land from damage. By drawing off the water from the hill land through proper drains in the bottom of the draws, much less water would reach the Poudre bottoms as seepage. The larger tracts of land in the draws and Poudre bottoms should be thoroughly tiled. The shallow basins and sinks offer the most serious difficulties in the construction of drains. Where the basin has a shallow depth the expense of cutting an outlet for the water may be slight, but where the basin is deep the expense of cutting an outlet is liable to be great.

SUMMARY.

Considerable damage has been felt in parts of the Poudre Valley from wet or alkali soils. Such wet or alkali tracts are the natural result of poor drainage. Tile drains should be installed in all the lower lands both to remove the excess of water and to prevent the accumulation of alkali. With continued irrigation of the uplands the amount of possible damage to the lower lands is very great and to insure against this damage the drainage should be commenced at once.

SOIL SURVEY IN THE CONNECTICUT VALLEY.

By CLARENCE W. DORSEY and J. A. BONSTEEL.

INTRODUCTION.

In the present appropriation bill for the United States Department of Agriculture, Congress has specifically authorized the mapping of the soils of the principal tobacco areas of the United States. On the 1st of July, 1899, the Secretary of Agriculture authorized this work to be started in the Connecticut Valley. About three and a half months were spent in surveying the soils of a portion of the valley.

The area is comprised within north latitude 41° 40′ and 42° 17′, and west longitude 72° 30′ and 72° 45′. It extends from South Glastonbury, Conn., where the valley pinches together, northward for a distance of about 41 miles, to Bachelor Brook, in South Hadley, Mass., where the Mount Holyoke range of mountains completely separates it from the extension of the valley from Northhampton northward into Vermont. The valley has an average width of from 5 to 10 miles on either side of the Connecticut River. The area surveyed and mapped comprised approximately 400 square miles, or 256,000 acres.

The object of the work was primarily to investigate and map the different tobacco soils, but incidentally all soil areas were surveyed. Rather full notes were taken as to the general condition of agricultural practice in the valley, the condition of labor, the improved implements used, the construction of barns and other farm buildings, transportation, and other matters contributing to the agricultural features of the locality. Particular attention was paid to the kind of tobacco and the influence of the different soils upon the texture and quality of the tobacco. As this soil work, however, is but the basis of a very extensive and systematic investigation into the physiology of the tobacco, and into the possibilities of changing the type and character of the tobacco through cultural methods and fermentation by the tobacco expert of the division, many of these notes will be reserved for future publication by the division, enough only being given here to make the soil work intelligible and interesting.

One feature which has been very clearly recognized in the course of the survey is the continual and rapid encroachment of city and suburban development for summer residences and for industrial purposes.

Many extensive areas which were formerly considered agricultural lands are now built up or held for speculative purposes for residence or industrial pursuits.

TOPOGRAPHY OF THE VALLEY.

The Connecticut Valley is bounded on either side by hills rising to an elevation of 50 to 100 feet above sea level in the neighborhood of Hartford, and to a little over 500 feet in the northern extension of the area. The difference in the elevation of the river from the upper to the lower portion of the area is but slight, and few falls or rapids occur within this distance. Some water power, however, is developed at a few places along the river. The country is level or gently rolling, sloping gradually back to the high rounded hills and low mountains which form the boundaries of the valley. At places there are still well-defined terraces with sharp escarpments with elevations varying from 10 to 100 feet above sea level.

GEOLOGY.

The origin of the soils is partly glacial, which is seen in the great drumlins, or hogbacks as they are called, and the heterogeneous mass of bowlders, sand, and clay bordering the valley and derived from all sorts of rocks; and partly from a shallow glacial lake which is supposed to have spread out over the valley from a dam somewhere below Hartford. Into this lake sediment was brought by rivers and streams. This sediment was sorted over and spread out more or less evenly over the bottom of the lake. As is usual in such cases the deeper and quieter portions of the lake received the finer sand and clays, while the coarse sand and gravels were deposited near the shore line and near the mouths of rivers. These deposits were evidently laid down during the glacial epoch, as arctic plants and leaves are occasionally found in the thin layers of clay and shale, indicating a very different climate than that which now prevails.

After the lake was drained the Connecticut River and its tributaries commenced cutting a series of terraces through the valley. These terraces are not very well preserved, and can not be followed for any great distance, but they are very plain in certain parts of the valley. The character of the formations laid down in these two ways will be described more at length in connection with the soils.

CLIMATE.

The temperature of the Connecticut Valley ranges from 56° F. in May, to 61° in September, with an average of 70° in July, which is the hottest month of the year. The mean maximum temperature ranges from 69° in May to 82° in July, with a mean daily range of 20°. There is on an average about 4.5 inches of rainfall during each month of this

PLATE XXI.

ESCARPMENT BETWEEN PODUNK FINE SANDY LOAM AND THE CONNECTICUT MEADOWS.

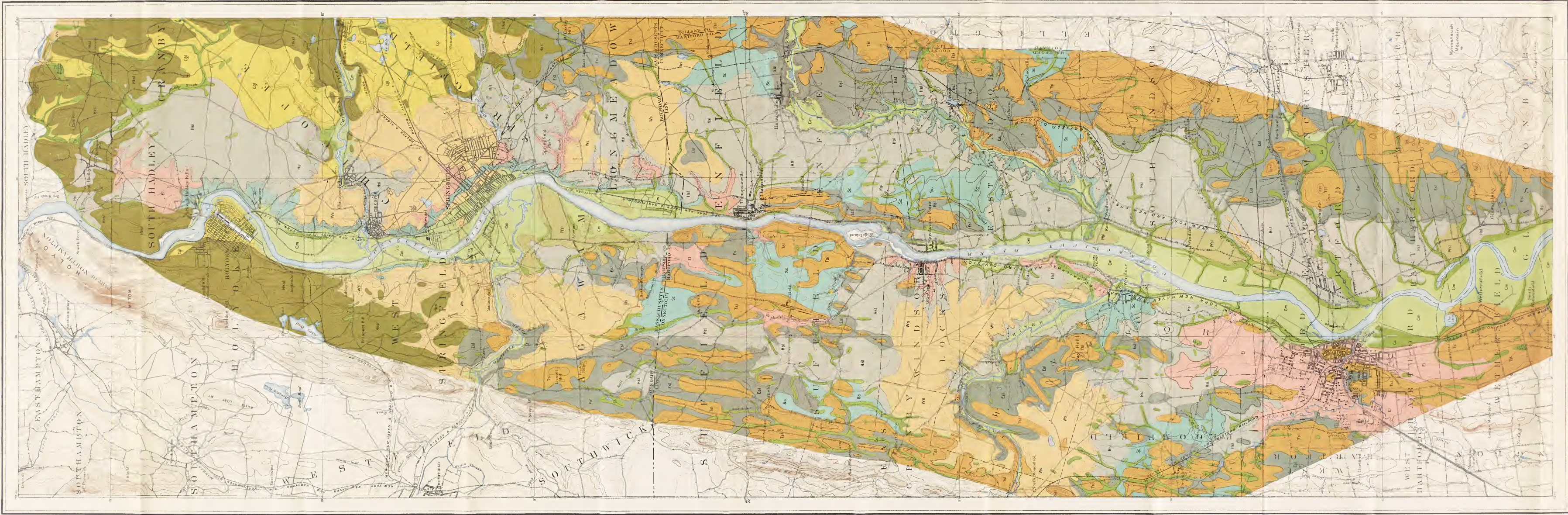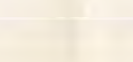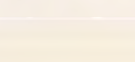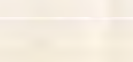The old terraces are sometimes very sharply marked.

SOIL MAP

CONN. AND MASS.
HARTFORD SHEET

LEGEND

H. Doc. N°. 56.1
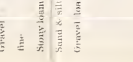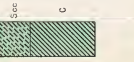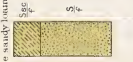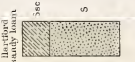
son, while the mean relative humidity during June, July,
is about 70 per cent.

; these conditions with the climatic conditions of the other
icts of Cuba, Sumatra, Florida, and Pennsylvania, it would
he temperature is sufficiently high for the production of
pper or filler leaf. The rainfall appears to be sufficient,
s well distributed during the season; but the daily range
re is much greater than occurs in either Cuba or Sumatra,
y likely has a great deal to do with the character of the
so great a daily range it would tend to thicken the leaf and
body. This is counterbalanced, to a large extent, by the
character of the soil, which is naturally adapted to the pro-
thin leaf, provided a rapid and uninterrupted growth can
d.

TOBACCO.

nteresting and most prominent feature in the agriculture
ecticut Valley is the tobacco industry, which has given a
eputation to the locality, and has provided work and sus-
large number of people.

as introduced into the Connecticut Valley as a recognized
the early part of this century. It was early recognized
ed greatly in its qualities from the Maryland and Virginia
t had less nicotine, less body, and was not so well adapted
king or to chewing. It is an interesting historical fact
t cigars made in this country are reported to have been
Connecticut Valley about the year 1802. It may be said
the home of the domestic cigar tobacco, as it certainly
e of the domestic cigar manufacturing.

specialization which has since developed in all lines of
istry the Connecticut tobacco has taken its place essen-
rapper leaf, and it is not used to any extent at the present
rs in domestic cigars. It is essentially a light wrapper,
rk, heavy wrappers were in style, as periodically happened,
fore the wide introduction and extensive use of the ideal
pper, the cultivation of tobacco in these light soils of Con-
largely abandoned and the domestic supply of wrapper
m the heavier soils of Pennsylvania. The torn, coarse, or
s are used as binders, while the trash and waste from the
ting tables are exported mainly to England and brings
nts per pound.

teristics of a good wrapper leaf, as described by Mr. Floyd,[1]
ould have but little body, little aroma or flavor, should be
so that it will stretch and cover well, and have good tex-
nd style, in order that it will appear well on the cigar.

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[1] Report No. 62, U. S. Department of Agriculture.

The leaves must be of uniform color and not too large, the 14 to 16 inch leaves being the most desirable sizes.

While the Connecticut tobacco has long been recognized by the trade as the most desirable domestic tobacco for wrapper purposes, yet the difference in price shows at once how the tobacco is regarded by manufacturers in comparison with the imported leaf. The Connecticut tobacco is worth, on an average, about 18 or 20 cents per pound; the Sumatra tobacco, imported exclusively for wrapper purposes, pays a duty of $1.85 per pound and sells on the market for from $2.50 to $3 per pound, duty paid. The Connecticut leaf is too large for an ideal wrapper, being often from 26 to 30 inches in length, the veins are very large, and only the tip of the leaf is suitable for high-priced cigars. Either on account of the physiology of the leaf or in the method of case sweating the desirable grain, color, and style are confined to the tip of the leaf, the lower half being glossy and very undesirable for wrapper purposes. This makes a great deal of waste, which can only be marketed in foreign countries at an exceedingly low price. Lastly, the tobacco is more highly flavored than is desirable for wrapper purposes and frequently masks the desirable qualities of the filler used in the cigar. These defects, as already stated, are to be made the subject of an exhaustive inquiry in the Division of Soils.

One of the objections urged by the manufacturers against the Connecticut tobacco, a fact which certainly largely reduces the price paid for the crop, is the unevenness of color and the poor grading as to color, length, and quality of leaf. In order to maintain a uniform brand of cigars, a manufacturer is forced to purchase a large amount of Connecticut leaf from which to select. Furthermore, on account of the difference in length and in texture of the leaves, there is considerable waste, which is difficult to estimate. It is hard to plan, therefore, for an economical use of the product when a purchase of this tobacco is made. This is not the case with the carefully sorted Sumatra.

One of the reasons which makes the quality of the leaf uncertain and varied is believed to be the method of fermenting in cases, the result of which is largely uncertain and dependent upon chance conditions, which are difficult to understand and impossible to properly control. It is believed by the tobacco experts of the Department that the bulk method of fermentation, as practiced in Florida and in Cuba, will give much more uniform and more desirable results.

The principal reason why the assortment and grading are not so closely done is the high cost of labor. There is so much demand for labor in the shops and factories that the farmer is forced to pay a high price for help. The most successful farmers, therefore, have been those who have cultivated small tracts of from 5 to 15 acres in extent and have made the crop by themselves, with such help as their families could supply, and with occasional hired labor. The Connecticut farmer has to pay about $1.50 per day, where the Florida planter pays about

50 cents per day for labor. It has always been found, however, that in the exhilarating climate of the North the more energetic laborers do so much more work in a given time and to so much better purposes that successful competition is possible in many lines along which at first sight the outcome would appear at least uncertain. It must be remembered, furthermore, that much of the most successful tobacco growing in Connecticut is done by the farmer and his family, so that a better system of fermentation and of sorting and grading could be done by them during the slack time of the winter months, when other work was not pressing, and without greatly increasing the actual expenditure of money in the production of the crop.

In Sumatra the cost of labor is very much less, even, than in Florida, and this is one reason why the Sumatra planters are able to give the extreme care to the assortment and classification of their tobacco. It must be remembered, also, that in a fancy assortment of well-cured and choice tobacco the price is largely speculative, as there is no sharp basis upon which to fix a commercial value. When from the superior excellence of the leaf the price goes beyond 30 cents per pound it is liable to increase in wider and wider units to $1, $2, and even $3 or $4 per pound, according to the fancy of the purchaser and the skill of the producer in working up a trade and supplying special demands. This has been shown in a very marked way in the development of the tobacco industry in Florida, where high prices are obtained by a few packers who understand the market requirements and can judiciously place their products, while a very low price is obtained by the average grower, who is less able or less willing to make the product required by the trade, and who is unable to make advantageous trade connections.

There is one interesting feature in regard to the tobacco industry in the Connecticut Valley, namely, that through the improved methods of planting and cultivating the crop the season of growth is being very materially shortened. In 1899 the growing season was about two weeks shorter than was ever known before. Tobacco set out the middle or last of May was fully matured by the middle of July.

SOILS.

The object of the soil survey is to classify and map the soils according to any condition which might influence the character of the vegetation, especially the character of the tobacco, the kind of crops adapted to the land, and the quality as well as the quantity of the crops grown. The soils of the Connecticut Valley have been classified in this way as a result of the season's work, and a map has been prepared, accompanying this report, showing the area and distribution of the various types of soils which were recognized. As before stated, this work will form the basis for a more extensive investigation of the Connecticut tobacco, and, pending such fuller investigation in regard to the character of the tobacco, only brief mention will be made at this time of the

relation of the soils to the character of the leaf which they produce. So many other questions enter in regarding the variety of seed used, the method of cultivation, fertilization, and fermentation, as well as the personal equations of the growers, that require the careful investigation and judgment of the tobacco expert, that only passing mention should be made at this time and in this connection of the character of the crop produced on the different soil areas.
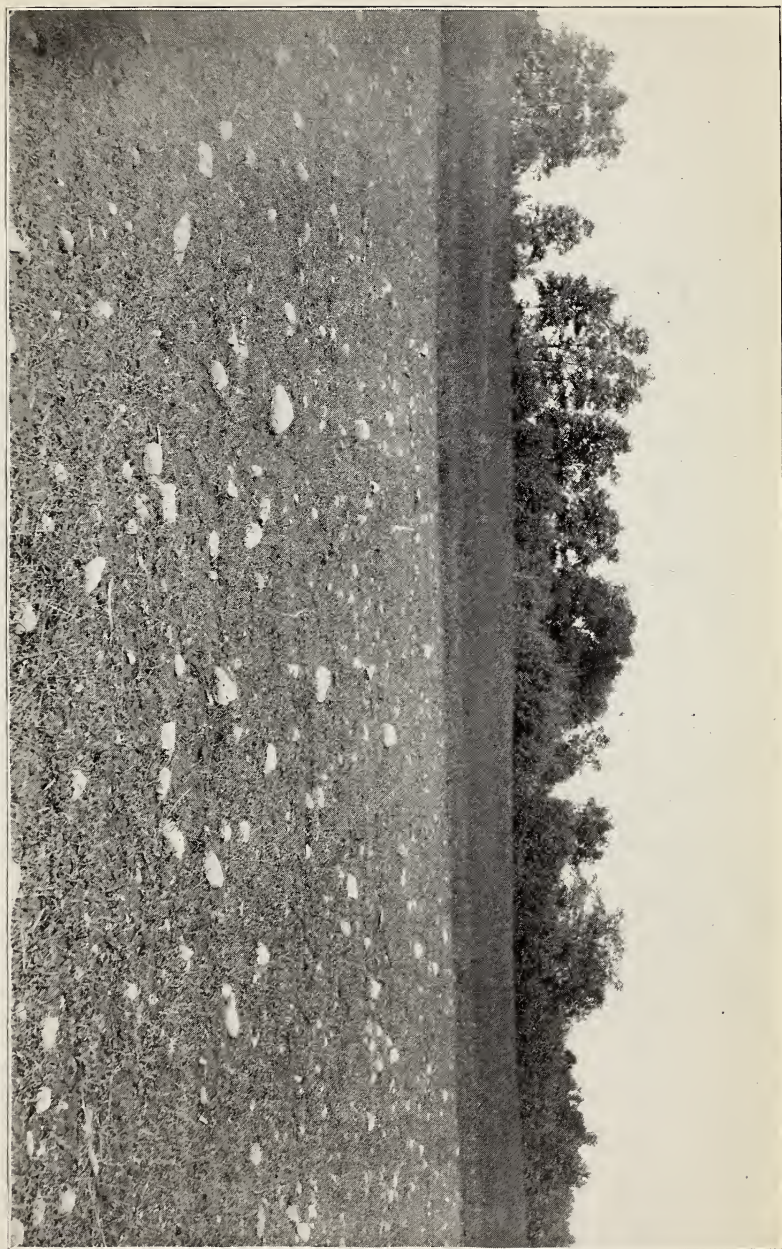
TRIASSIC STONY LOAM.

As already mentioned, the Connecticut Valley is bounded on either side, from the southernmost part of the area surveyed up to Westfield and Mill River, just below Springfield, by a glacial deposit consisting mainly of Triassic sandstone débris forming long lenticular hills, drumlins, or hogbacks, between which the surface is rolling and hilly, with a few long ridges and groups of rounded hills varying in elevation from 40 to 400 feet. A few areas of this glacial débris are scattered about in the valley proper, and from the fact that they are not covered with lake sediment it may be assumed that they were formerly islands in the glacial lake, or else the covering has since been removed by erosion.

The Triassic stony loam soils are fine sandy loams, dark Indian red in color, mixed with gravel and bowlders of all sizes and shapes, varying in size from an inch to 6 or 8 feet in diameter. The amount of gravel and undecomposed rock exceeds 5 per cent in all cases, and may exceed 50 per cent. In many cases fields are now comparatively free from these bowlders and large rocks on account of the numerous times they have been picked over and stones removed. Indeed, the surface of this geological area has been very greatly modified by the hand of man. Cultivated fields may contain only a few scattered stones, while the surface of the area surrounding the field may be covered with a mass of stones and bowlders. The stones, especially the smaller ones, and the fine gravel are derived principally from the Triassic sandstone and shales.

Tobacco is grown to a considerable extent in certain areas in the Triassic stony loams. It is considered a fat tobacco, and has an undesirable cinnamon color, but it is readily bought up at good prices for special market demands. The character of the tobacco is quite different from that grown on the other tobacco soils of the valley, and there is a long-standing controversy as to the relative merits of this and of the tobacco from other soils. The fact of the matter is that they are used largely in different channels, and are to a great extent bought up by different dealers. There are large tobacco centers around Day Hill, south of Poquonock, around Warehouse Point, Suffield, and Enfield street. The best development of the tobacco industry on this formation is probably around Suffield and Warehouse Point. The Havana seed is exclusively grown on this formation. The other areas outlined on the map have soils of fair condition, but are not farmed to any great

PLATE XXII.

TRIASSIC STONY LOAM.

These stones are picked off year after year to provide for cultivation.

PLATE XXIII.

A DRUMLIN OR HOGBACK OF THE HOLYOKE STONY LOAM.

extent. They are given up mainly to pasture lands, meadows, and orchards. The following table gives the mechanical analysis of the Triassic stony loam subsoils:

Mechanical analyses of subsoils of Triassic stony loam.

(Fine earth.)

Diameter.	Conventional names.	4211. Bloomfield, ½ mile S.	4212. Enfield.	4201. Hazard-ville, 1½ miles S.
Millimeters.		*Per cent.*	*Per cent.*	*Per cent.*
2 to 1	Gravel......................	2	12.45	5.26
1 to 0.5	Coarse sand................	3.35	11.86	8.66
0.5 to .25	Medium sand...............	8.60	13.98	18.83
.25 to .1	Fine sand..................	31.25	14.78	21.00
.1 to .05	Very fine sand.............	34.22	17.51	18.83
.05 to .01	Silt......................	4.35	8.20	8.70
.01 to .005	Fine silt..................	6.20	8.67	5.30
.005 to .0001	Clay......................	6.57	10.23	10.87
	Loss at 110° C.............	1.36	1.04	1 01
	Loss on ignition...........	2.03	1.69	1.77

·HOLYOKE STONY LOAM.

The hills bounding the northern extension of the area examined, with elevations from 240 to 500 feet above sea level, are likewise glacial deposits, but formed of diabase, crystalline, and metamorphosed rocks. The surface of the country of what may be called the foothills is rolling with steep slopes and containing many lenticular hills and groups of rounded hills. The surface is rough, and in places large masses of bowlders are lying as they were piled by the ice, and with hardly any perceptible disintegration. Many of the slopes are entirely covered with these bowlders. The soil is a sandy loam, containing from 10 to 50 per cent of gravel and bowlders, ranging in size from 1 inch to 12 or 15 feet in diameter. The following table gives the mechanical analysis of the fine earth of a sample of Holyoke stony loam:

Mechanical analysis of subsoil of Holyoke stony loam.

Diameter.	Conventional names.	4203. Ashleyville, 2 miles S.
Millimeters.		*Per cent.*
2 to 1	Gravel..................	3.05
1 to 0.5	Coarse sand	3.85
0.5 to .25	Medium sand............	8.22
.25 to .1	Fine sand...............	11.53
.1 to .05	Very fine sand..........	29.82
.05 to .01	Silt...................	21.26
.01 to .005	Fine silt...............	6.45
.005 to .0001	Clay	12.20
	Loss at 110° C..........	1.54
	Loss on ignition	2.35

The soils are derived entirely from the glacial débris. The soils are not fertile, and are not farmed to any great extent. There are occasional patches of corn, oats, and rye, but no tobacco. They are mainly given up to stony pastures and orchards.

WINDSOR SAND.

The generally accepted idea of the origin of the soils of the valley proper has already been referred to. It is supposed that during glacial times a dam extended across the valley below Hartford, forming a shallow lake of considerable extent, and comprising all of the area which has been surveyed this season. The streams collecting the drainage from the surrounding country emptying into the lake brought sediments, which were sorted over and deposited in different places, according to the direction of the currents, the depth of the lake, and the velocity of the water. The coarser sands and gravels would be deposited near the shore line and the mouth of the streams, while the finer sands and clays would be deposited off shore, and in deeper and quieter portions of the lake.

As the level of the water of the lake was lowered from time to time well-marked shore lines, constituting terraces, were formed out of the material which had previously been deposited, and out of fresh material which had been emptied into the lake. This gave rise to a series of terraces, more or less well preserved at the present time, but greatly cut up and modified by recent stream action, and by the meanderings of the Connecticut River.

The Windsor sand represents what is supposed to be the original bottom of the old glacial lake in its shallowest parts. The soil is composed of yellowish-red or brown sand, resembling a coarse sharp building sand, and containing less than 5 per cent of clay. The material contains about 5 per cent of coarse gravel, ranging in size from 2 to 10 mm. in diameter. This gravel content increases to some extent in the subsoil. In places this formation is 40 feet deep. The following table gives the mechanical analyses of four samples of Windsor sand:

Mechanical analyses of subsoils of Windsor sand.

Diameter.	Conventional names.	4210. Bloomfield, 2 miles SE.	4198. Windsor Locks, 3 miles SW.	4199. Hubbards Corners, 1½ miles NW.	4200. Chicopee, 2 miles SW.
Millimeters.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
2 to 1	Gravel....................	4.98	8.00	2.52	14.30
1 to 0.5	Coarse sand..............	11.31	15.83	12.32	26.28
0.5 to .25	Medium sand.............	33.41	39.90	39.29	30.35
.25 to .1	Fine sand.................	33.75	22.21	27.92	9.55
.1 to .05	Very fine sand............	10.82	6.56	7.30	6.02
.05 to .01	Silt......................	2.09	3.20	4.33	4.66
.01 to .005	Fine silt.................	1.03	1.20	1.62	2.73
.005 to .0001	Clay	1.65	2.25	3.15	4.87
	Loss at 110° C	.50	.45	.48	.50
	Loss on ignition	.80	1.00	1.84	1.47

The soils are coarse and inclined to be leachy or droughty, but, like many soils of this character, are generally somewhat moist beneath the top few inches of dry sand throughout the most severe drought. The soils are good representative truck soils and are used for this purpose in some parts of the area.
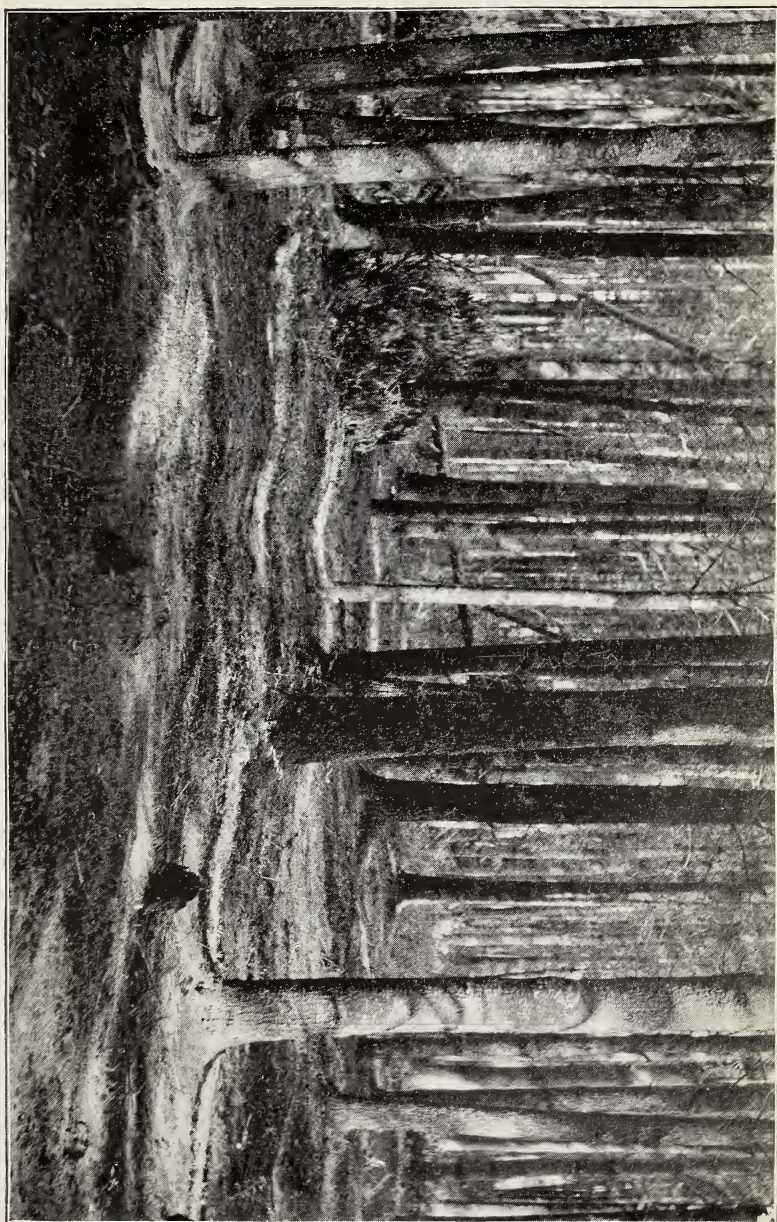
Windsor Sand showing Old Corn Rows covered with Forest Growth.

The sand is so porous that the rain sinks into it as rapidly as it falls.

In favorable seasons a very fine quality of thin-leaved silky tobacco is produced on these soils, the finest probably that is produced on any of the soils of the valley, but the season has to be just right, and such favorable conditions hardly occur more than two years out of five. If a crop by any means can be kept growing rapidly and continuously, it will produce a fine silky leaf excelled by none of the other soils in the valley. In average seasons, however, the growth is liable to be checked by changing weather conditions, and the plant is small and produces a leaf which is thick and strong. It is desirable to plant early on these lands and give constant and thorough cultivation.

The Windsor sand comprises a large part of the Windsor Plains in the towns of Windsor, Bloomfield, East Granby, and Windsor Locks, as well as a small area in East Hartford. The surface of the area in Connecticut is level or gently rolling, ranging from 100 to 180 feet in elevation. The area in Massachusetts is much larger and covers in all about 30 square miles. It is largely developed in the towns of Agawam, West Springfield, Springfield, Chicopee, and Long Meadow. The surface is much more rolling than in Connecticut; and ranges in elevation from 100 to 240 feet.

For the most part the area of Windsor sand is not very extensively cultivated at the present time. In Agawam there is some truck farming, a few peach orchards, and some tobacco grown. East of Springfield the area is rapidly building up in the extension of the city. In Connecticut there are but few houses, deep sandy roads, and many old and unsuccessful fruit farms. Many areas which were formerly cultivated are now grown up in the characteristic forest growth of pine. The soil is so open and porous and offers so little resistance to the entrance of rain water that the surface hardly washes at all, and there are old corn rows running through the forests and well preserved, upon which the trees must be at least 50 to 80 years old. Many of the old furrows thrown up in the original measurement of the land are still plainly distinguishable.

HARTFORD SANDY LOAM.

The Hartford sandy loam occupies by far the largest extent, and plays the most important part in the tobacco industry in the Connecticut valley. It extends from Glastonbury to South Hadley, and covers in all an area of over 80 square miles. A portion of it is probably the undisturbed old lake bottom, but there are also more recent river-cut terraces. The formation occurs in broad terraces, which are very level in places and gently rolling in others. The formation is found at elevations ranging from 30 to 260 feet above sea level. The soils are red, brown or yellow, medium grade sandy loams, about 12 inches deep, underlaid with yellow sands, containing little or no organic matter. The soil is a grade finer than the Windsor sand, as is apparent from the analysis, and is correspondingly stronger, and decidedly safer as an agricultural soil. The deposit varies in depth from about 3 feet to 20

feet. It differs again from the Windsor sand in having no gravel, or but a mere trace of very fine gravel in a few places. The following table gives the mechanical analyses of five samples of Hartford sandy loam:

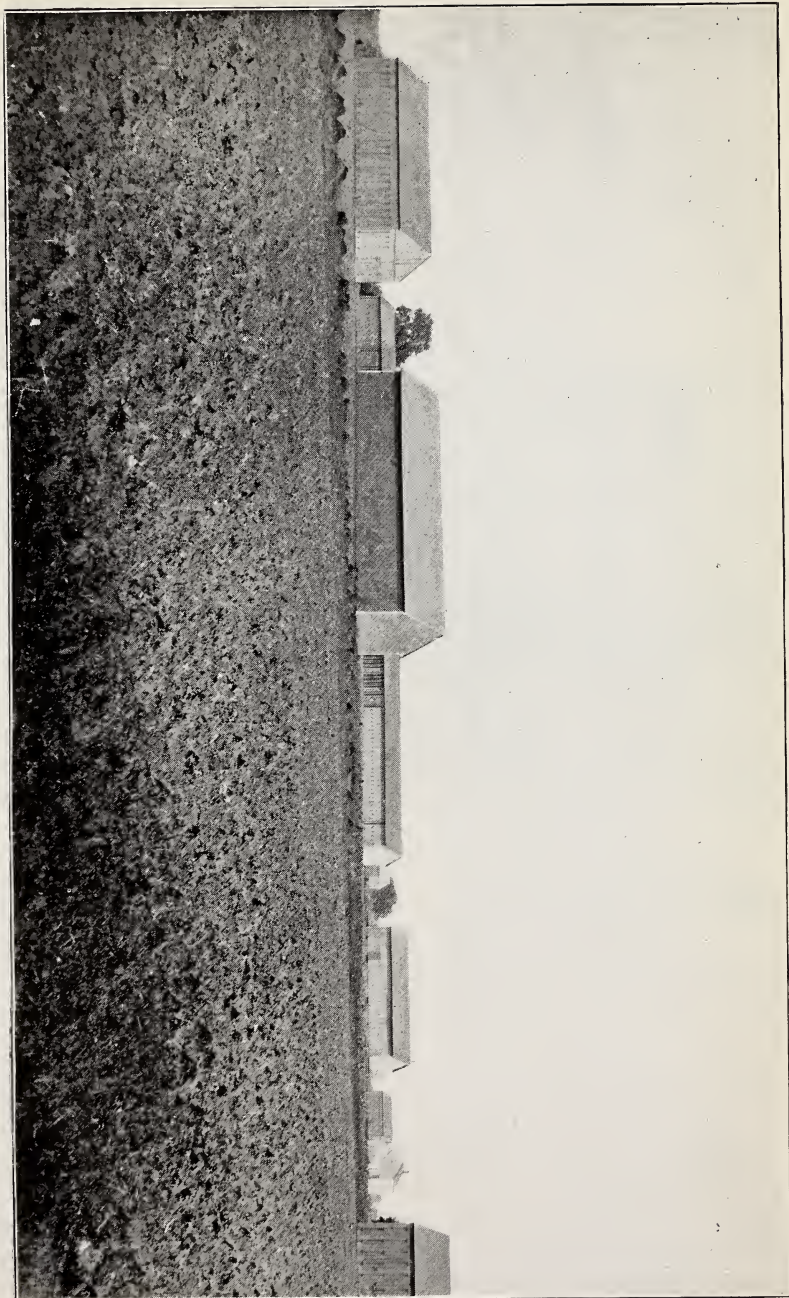*Mechanical analyses of subsoils of Hartford sandy loam.*

Diameter.	Conventional names.	4204. Windsor, SW.	4205. East Long Meadows, 2 miles NW.	4214. Burnside, ½ mile SW.	4213. South Windsor, 2 miles E.	4215. Burnham, 1 mile E.
Millimeters.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
2 to 1	Gravel..................	2. 20	0. 00	2. 23	Trace.	4. 11
1 to 0. 5	Coarse sand	7. 51	. 31	7. 73	6. 84	11. 83
0. 5 to . 25	Medium sand...........	33. 50	2. 84	25. 25	42. 86	29. 20
. 25 to . 1	Fine sand...............	32. 05	63. 10	29. 00	33. 00	24. 45
. 1 to . 05	Very fine sand..........	13. 50	29. 15	25. 40	7. 73	12. 72
. 05 to . 01	Silt.....................	4. 47	1. 15	3. 45	2. 63	3. 48
. 01 to . 005	Fine silt................	1. 75	. 96	2. 10	1. 70	3. 28
. 005 to . 0001	Clay	2. 78	1. 42	3. 22	3. 50	5. 20
Loss at 110° C......................		. 80	. 50	. 77	. 75	2. 95
Loss on ignition....................		1. 30	. 90	1. 27	1. 54	2. 81

The general crop of Connecticut seed-leaf tobacco is grown on these soils. This represents what may be called the typical tobacco soil of the Connecticut Valley, and the safest and therefore the best soil at least for the seed-leaf variety. Corn and potatoes do well on these soils, and about Hockanum and south of Willow Brook, in East Hartford, considerable truck farming is carried on. Southwest of Hazardville the soil for some reason appears less coherent, and drifting sand dunes are common. The yield of tobacco on this soil varies from 1,500 to 2,000 pounds per acre, or even a little more. The average price of the crop is about 18 cents a pound, but the lands are heavily fertilized. Labor is high and the crop as a whole is expensive to make. Tobacco is grown mainly in small fields of from 3 to 10 acres, 15 acres being an unusually large tract. There are many large areas of this still undeveloped upon which a good quality of tobacco can be produced:
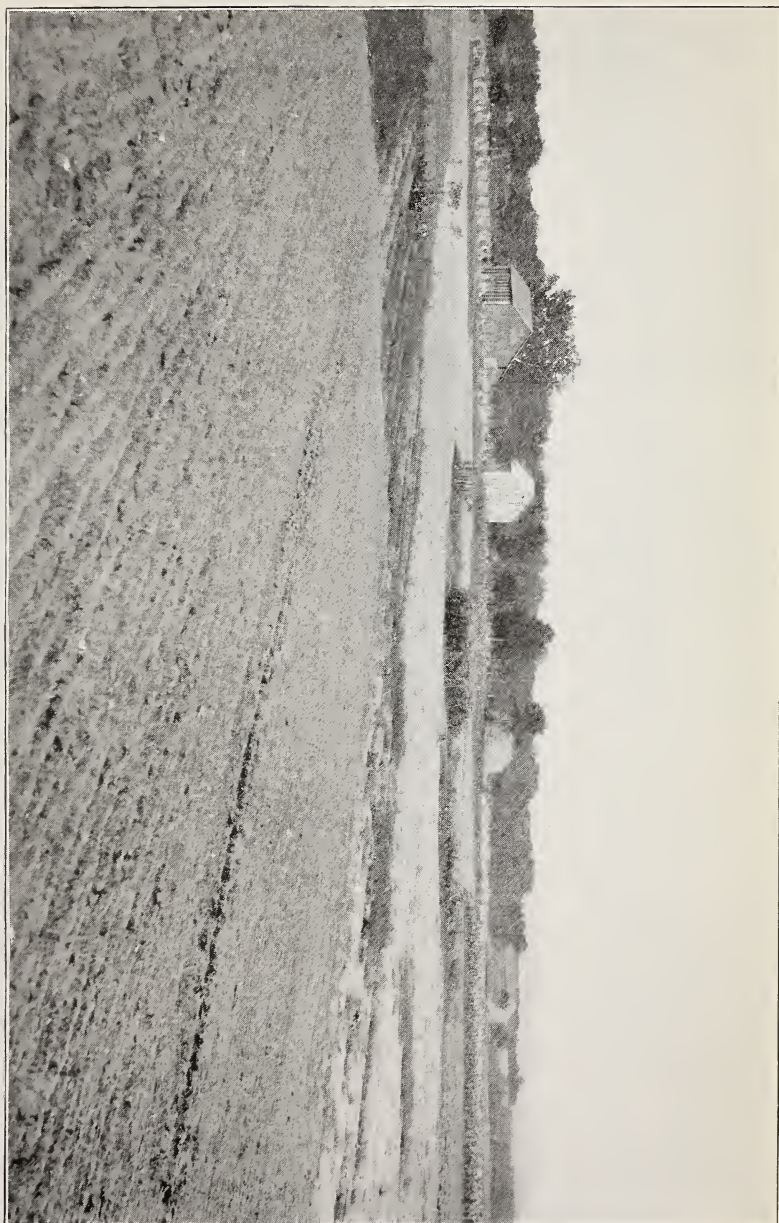
PODUNK FINE SANDY LOAM.

The Podunk fine sandy loam represents river cut terraces, ranging in elevation from 20 to 80 feet above sea level. There is in all an area of only about 7 or 8 square miles of this in the area surveyed, and of this only about ½ square mile in East Hartford has contributed largely to the fame of the Connecticut Valley in the production of the broad-leaf variety, which differs in many essential characteristics from the Habana seed-leaf grown on the Hartford sandy loam. The surface of the areas are level or very gently rolling. The soil is a dark-brown sandy loam, about 12 inches deep, and of most excellent tilth. The subsoil is a dark-brown sandy loam of the same texture as the soil, but differing in color, as it has less organic matter. The following table gives the mechanical analyses of two samples of Podunk fine sandy loam:

PLATE XXV.

PODUNK BROADLEAF TOBACCO AREA.

PLATE XXVI.

THE HARTFORD SANDY LOAM.

Mechanical analyses of subsoils of Podunk fine sandy loam.

Diameter.	Conventional names.	4206. Agawam, 1 mile N W.	4216. South Windsor, ½ mile N E.
Millimeters.		*Per cent.*	*Per cent.*
2 to 1	Gravel......................	0.00	0.50
1 to 0.5	Coarse sand	.07	1.51
0.5 to .25	Medium sand...............	1.53	7.96
.25 to .1	Fine sand	41.80	23.27
.1 to .05	Very fine sand..............	49.00	41.82
.05 to .01	Silt.......................	3.43	9.15
.01 to .005	Fine silt...................	1.02	6.32
.005 to .0001	Clay	1.70	4.40
Loss at 110° C..........................		.66	1.92
Loss on ignition........................		1.08	3.68

The soils are a grade finer in texture than the Hartford sandy loams, and while well drained are strong, safe, and productive. The areas are all thickly settled, and, with the exception of that in the town of Agawam, are very highly cultivated and well cared for. The South Windsor and Naubuc districts, particularly, are famous broad-leaf tobacco areas.

The broad-leaf variety is heavier and has a thicker leaf than the seed-leaf, is generally darker in color, and is a better leaf for cutting purposes. It has not the undesirable "seed" flavor of the Habana seed-leaf, and is preferred by many smokers. It yields more per acre than the Habana seed on the Hartford sandy loams, but, with all, it has a rougher look in the cigar. For this reason it is not in such good favor with many cigar manufacturers as the finer, silkier Habana seed grown on the Hartford loams. It is considered better by the farmers in this Podunk region to plant tobacco continuously rather than to use a rotation. There are fields which have been continuously in tobacco for twenty-five years, and which it is claimed are as productive and produce as fine tobacco as at any period of their cultivation. This broad-leaf variety is grown to a limited extent upon the small area of Hartford sandy loam east of Connecticut River, near South Windsor, but, with this exception, it is confined to the Podunk soil. Corn and potatoes do well on this soil. The Agawam area has not been very successfully farmed for the past few years, for some unexplained reason, and there is a chance of development there which should certainly arrest the attention of tobacco growers.

CONNECTICUT MEADOWS.

The Connecticut meadows occur as narrow strips on either side of the Connecticut River from Holyoke south to Long Meadow, Mass., and from Warehouse Point to South Glastonbury, Conn. There are smaller areas along the various tributaries of the Connecticut River. This represents the present flood plain of the Connecticut River and its tributaries, being built up at the present time by deposits from the flood

waters. The river will finally build up this terrace so high that it can no longer spread over it, and new terraces will be constructed at lower levels. The surface of the meadows is generally higher along the river bank and, of course, better drained there. There is a gentle slope down to the scarp connected with the upland or next higher terrace, and this area immediately below the upland is frequently wet and swampy. The meadows are all subject to overflow at time of very high flood, but in spite of this there is considerable farming on them, although at some risk of the loss of the crop. Surface of the meadows is level or gently rolling, with occasional old stream channels or run-ways in them. The surface of the meadow is from 5 to 20 feet above sea level at Hartford and from 40 to 80 feet above sea level at Springfield and Holyoke. The material of which the soils are composed has been brought in by the rivers at flood time, but there is no evidence of stratification, probably on account of the wind and rain action between the comparatively long periods between the floods. The character of the material is very uniform throughout all the areas. It is very fine sand and silt, being uniform in places to a depth of 10 feet and over, resembling loess in many of its characteristics. It is a grade finer than the Podunk fine sandy loam. The soil is from 16 to 18 inches deep, contains a large amount of organic matter, consists mainly of very fine grades of sand and silt with but little clay, and is considered extremely fertile and productive. The subsoil is grayish in color, but otherwise hardly different from the overlying soil. The following table gives the mechanical analyses of four samples of subsoil from the Connecticut meadows:

Mechanical analyses of subsoils of Connecticut meadows.

Diameter.	Conventional names.	4207. Chicopee, 2½ miles N.	4217. Hartford, ¾ mile SE.	4218. S. Windsor, ⅛ mile NW.	4219. Windsor, ½ mile SE.
Millimeters.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
2 to 1	Gravel	0.00	0.00	0.00	0.00
1 to 0.5	Coarse sand	Trace.	Trace.	Trace.	.00
0.5 to .25	Medium sand	0.37	0.21	0.36	.31
.25 to 1	Fine sand	6.87	1.50	2	1.77
.1 to .05	Very fine sand	50.86	19.55	14.78	9.79
.05 to .01	Silt	28.49	33.67	36.50	30.25
.1 to .005	Fine silt	6.60	28.54	27.17	29.47
.005 to .0001	Clay	3.35	9.50	13.40	19.11
	Loss at 110° C.	1.10	2.60	2.50	4.13
	Loss in ignition	2.60	4.75	3.54	5.31

Generally the meadow soils produce a dark, heavy, low grade of tobacco. When dark cigars were in style, as they were fifteen or twenty years ago, these meadow lands produced a tobacco which was much more in favor than it is at the present time. Very good tobacco can be grown on high meadow land if it be well drained, but there is an almost universal prejudice against it and it brings a low price from the mere association with the name of meadow land. There is an area of high meadow land west of East Windsor hill which is never overflowed

PLATE XXVII.

A TYPICAL TOBACCO BARN OF THE CONNECTICUT VALLEY, 180 FEET LONG.

by the river, resembling the Podunk fine sandy loam and classed with it, upon which there is a very good quality of tobacco produced, but which suffers from the mere association with the name of meadow land.

A large proportion of the Connecticut meadows is used only for grass, several crops being cut in the course of the year. Areas where very well drained are used for corn and potatoes, and in some cases for celery and general truck farming. Below Merrick the meadows are diked to keep out the high water and insure the land from overflow, but this is the only place where this has been done to any extent.

The Connecticut meadows, Podunk fine sandy loam, Hartford sandy loam, and Windsor sand represent four important and representative soils of higher and higher average elevation and of coarser and coarser material, which represent the most extensive and most important soil areas in the valley. The difference in texture of these soils is very marked and very apparent to the eye, and this difference in texture determines to a large extent the relation of the soils to crops, and particularly to the quality of the tobacco produced.

ENFIELD SANDY LOAM.

On either side of the valley, in terraces around the hills of the Triassic stony loams and filling up depressions at elevations ranging from 80 to 240 feet, there is a fine sandy deposit, resembling the Hartford sandy loam, directly over the Triassic stony loams which occurs at a depth of about 2 feet below the surface. The outward extension of the terraces grades into the Hartford sandy loam, where the Triassic stony loam is 3 feet or more below the surface. The underlying Triassic stony loam provides a retentive subsoil, and these soils retain moisture better and are rather stronger than the Hartford sandy loams, which they resemble in other respects. The following table gives the mechanical analysis of a sample of Enfield sandy loam:

Mechanical analysis of subsoil of Enfield sandy loam.

Diameter.	Conventional names.	4202. East Hartford, E.
Millimeters.		*Per cent.*
2 to 1	Gravel......................	4.22
1 to 0.5	Coarse sand................	5.05
0.5 to .25	Medium sand...............	7.75
.25 to .1	Fine sand..................	10.43
.1 to .05	Very fine sand.............	43.60
.05 to .01	Silt.......................	13.53
.01 to .005	Fine silt..................	4.86
.005 to .0001	Clay	5.57
Loss at 110° C........................		1.82
Loss on ignition......................		2.22

A very good quality of Habana seed-leaf tobacco is grown to a limited extent on these soils, especially around Melrose, Osborne, Wapping, and south of Poquonock. The characteristic feature of this soil as distinguished from the Hartford sandy loam is the occurrence of the Triassic stony loam at a depth of from 12 to 24 inches. The areas along the eastern part of the valley are generally thickly settled. In other parts of the valley there are large areas still uncleared and uncultivated.

SUFFIELD CLAY.

The Suffield clays occur principally at Windsor, East Windsor, and Suffield, with occasional small areas along the scarp between the Connecticut meadows and the upland. These soils are found at elevations varying from 40 to 220 feet above tide. The surface is gently rolling, except along the scarps, where the slopes are liable to be quite steep. The soils are heavy clay loams, grading down into drab clays with exceedingly poor drainage, making the surface cold and wet. The following table gives the mechanical analyses of two samples of Suffield clay:

Mechanical analyses of subsoils of Suffield clay.

Diameter.	Conventional names.	4208. Suffield.	4209. Riverdale, W.
Millimeters.		*Per cent.*	*Per cent.*
2 to 1	Gravel...............	0.00	0.00
1 to 0.5	Coarse sand	.29	.00
0.5 to .25	Medium sand	.40	.00
.25 to .1	Fine sand............	.73	.15
.1 to .05	Very fine sand.......	5	11.27
.05 to .01	Silt.................	32.57	38.58
.01 to .005	Fine silt	29.10	24
.005 to .0001	Clay...............	25.65	23.50
	Loss at 110° C	2.17	1.10
	Loss on ignition.....	3.53	1.50

The Suffield clays have little value as agricultural lands, and are mostly given up to grass and pasture. There are large areas which are not cultivated at all, and growing up in a tangled mass of worthless underbrush. Around Springfield, Holyoke, and Hartford there are large brickyards making brick of this clay. No tobacco is grown in any part of this area, as the soils are entirely unsuited to this crop.

ELMWOOD LOAM.

The Elmwood loam occurs in large areas around Hartford, Windsor, and South Hadley. The soil consists of a deposit of fine yellow sandy loam, about 24 inches deep, overlying laminated drab clays, similar in all respects to the Suffield clays. The clay is a deep lake deposit, while the overlying sand is a shallow lake or river deposit. The following table gives the mechanical analysis of a sample of Elmwood sandy loam:

Mechanical analysis of subsoil of Elmwood sandy loam.

Diameter.	Conventional names.	4220. Elmwood, 3 miles N.
Millimeters.		*Per cent.*
2 to 1	Gravel........................	0.00
1 to 0.5	Coarse sand.................	0.45
0.5 to .25	Medium sand...............	3.76
.25 to .1	Fine sand....................	17.53
.1 to .05	Very fine sand..............	59.82
.05 to .01	Silt..........................	7.03
.01 to .005	Fine silt....................	4.65
.005 to .0001	Clay........................	4.00
Loss at 110° C		1.40
Loss on ignition.........................		1.90

The surface of the ground is rolling and hummocky. The soil is found at elevations varying from 20 to 80 feet above sea level at Hartford, and from 160 to 200 feet at South Hadley. Around Hartford the Elmwood loam gives fairly good grass and pasture lands, but is not cultivated to any extent except for small garden patches. North of Hartford it is neither cleared nor cultivated. The area around Hartford is rapidly being built up in the suburbs of the city. A few small areas have been cultivated in tobacco, above Windsor, but the soil is not adapted to tobacco cultivation.

CONNECTICUT SWAMP.

Considerable swamp land and wet meadows occur scattered over the entire valley at various elevations. They occur generally along the scarp between the Connecticut meadows and the upland and along a large number of small streams flowing into the Connecticut River. Again in the hollows between hills and slopes, where there is poor drainage, these upland swamps are liable to occur from any cause where the drainage is poor and the soil almost impervious to water, with swampy, wet conditions as a characteristic feature. No matter at what elevation they may be found these are all classed as Connecticut swamps. The swamps are all of fresh water and they are all at present too wet for cultivation. Some of the areas can be easily drained, while others immediately along the river could not be reclaimed except at great expense. Most of them along the river are wet throughout the year. Some of them are sufficiently dry during the summer so that the coarse, rank meadow grass produced may be mowed and saved for rough forage. The character of the soils of these areas has not been determined. They are very small in extent and of little agricultural importance. Many of them represent merely obstructed drainage areas which by underdrainage could readily be reclaimed.

COMPARISON OF THE TEXTURE OF THE SOILS.

The following table gives a clear idea of the texture of the soils of the Connecticut Valley, and explains to a great extent the distribution of crops and the difference in the characteristics of the tobacco grown on the different soil areas:

Windsor Plains, 65 per cent gravel to medium sand, 30 per cent fine and very fine sand.

Triassic stony loam, 35 per cent gravel to medium sand, 40 per cent fine and very fine sand.

Enfield sandy loam, 17 per cent gravel to medium sand, 55 per cent fine and very fine sand.

Diabase stony loam, 15 per cent gravel to medium sand, 40 per cent fine and very fine sand.

Hartford sandy loam, 65 per cent medium to fine sand, 90 per cent medium to very fine sand.

Podunk loam, 40 per cent fine sand, 90 per cent fine and very fine sand.

Connecticut meadows, 50 per cent very fine sand, 80 per cent very fine sand and silt.

Suffield clay, 35 per cent silt, 50 per cent fine silt and clay, 25 per cent clay.

APPLICATION OF THE THEORY OF SOLUTION TO THE STUDY OF SOILS.

By FRANK K. CAMERON.

INTRODUCTION.

In the course of the work of this laboratory within the last year we have had occasion to examine chemically quite a number of soils and soil crusts from the arid regions. These soils have been of the class known as "alkali soils"; that is, they contain a relatively large percentage of water-soluble salts. The origin and presence of these salts have been discussed in the publications of this Division and elsewhere, so that we may assume, for the purposes of this paper, that this part of the subject has been made sufficiently familiar to those who may be interested.

The salts which go to make up these crusts or water-soluble constituents of the soils are, in general, sodium chlorid, magnesium chlorid, calcium chlorid, sodium sulphate, magnesium sulphate, calcium sulphate, and sodium carbonate with, occasionally, much smaller quantities of other salts which may be regarded as relatively unimportant. It is usual to find several of these salt components together in an alkali soil.

When sodium carbonate is a component of the salts present then the salt mixture is known as "black alkali," because of the charring and caustic effect of the sodium carbonate on the organic matter present giving a characteristic black color to the soil. In contradistinction, when sodium carbonate is *not* a component, these salt mixtures are known as "white alkali," because, in general, they do not show this darkening effect but effloresce on the surface as a white crust if present in sufficient amount. It is to be remembered, however, that local terminology is not always in full accord with this distinction; for instance, in New Mexico, in the Pecos Valley, there are tracts of land, quite dark in appearance, containing much water-soluble salts or alkali, which are locally called "black alkali" land, although examination fails to show the presence of any sodium carbonate.

The chemical examination or analysis of these water-soluble salts in the soils yields results which, in many cases, seem very remarkable at first sight in the relatively large percentage of salts usually regarded as sparingly soluble—notably sulphates and carbonates of lime—and the question how they have been dissolved and transported in such large

quantities is a natural one. When we attempt to dissolve these salts in water, in order to remove them from the soil, just such surprising results are obtained in our solutions in the relatively large quantities dissolved under certain conditions. In order to understand these phenomena and to make our analyses intelligible it will be desirable to have in mind the laws governing solutions which apply to such cases.

NATURE OF SOLUTIONS.

Before discussing these laws it seems well to state more precisely what is understood by the term solution, and as we are concerned only with solutions of solids in liquids we shall not stop to make any modifications which other solutions would necessitate.

The most striking characteristic of a solution is its homogeneity; that is to say, after it has come to equilibrium every part of the solution is just like any other part in all its physical and chemical properties. Two important exceptions should be noted here. If the solution be one of considerable height or depth the gravitation force comes in evidence, the lower portions of the solution are more dense, the higher portions less so, and there is a corresponding variation in other properties. But even here it will be observed that there is no sudden break in the properties. They will vary regularly and continuously as we go from the top to the bottom. Again, it has been observed in the case of solutions in contact with solids (the walls of the containing vessel, for instance) that in portions very near the surface there is often a concentration of the dissolved material. This phenomenon has been called ad-sorption. The growth of crystals on the surface of solids introduced into the solution is probably due to this cause; the difficulty of washing certain solutions through a filter paper, where often a portion of the dissolved substance will linger after the most persistent washing, is a well-known example of this phenomenon.

Another important characteristic of a solution is that all its properties vary continuously with the concentration. The law by which this variation takes place in any specific case may not be evident, and in general it is not, but it may be taken as a well-established principle that there is no sudden jump or change of direction in any physical property, as the concentration gradually changes. The recognition of this fact has come within comparatively recent years. It was long supposed that, while this fact was in general true, there were well-marked exceptions. For instance, it has been known since the time of Gay-Lussac that the solubility of Glauber's salt (the decahydrate of sodium sulphate) changed suddenly at about 33° if the temperature was gradually raised. So do all the other physical properties of the solution; such as vapor pressure, refractive power, conductivity, etc. Within comparatively recent years the explanation was offered that below 33° the solution was one of the decahydrate in water, and above that temperature the solution was something different, containing a

lesser hydrate or the anhydrous salt. Later study has shown that this view must be modified. There is probably no change in the substance actually in the solution, for in that case we would expect some irregularities in the change of physical properties. The difference below and above this temperature point, 33°, is in the equilibrium between the dissolved substance and the undissolved salt which may crystallize from the saturated solution. It is really the nature of the undissolved salt at the given temperature when in contact with the solution that is the controlling factor, and we have in fact two solubility curves in this particular case which meet in a common point near 33°. When the solid decahydrate is warmed to this temperature it partially melts into a saturated solution of the anhydrous salt, the excess of anhydrous salt separating as such.

We are now familiar with quite a number of similar instances of this character, but in every case investigated a similar explanation has been demonstrated, and this characteristic of solutions has been thoroughly established as a natural physical law. Indeed, these two properties just described are incorporated in the best definition as yet proposed for a solution, i. e., a homogeneous mixture whose properties vary regularly with the concentration.

LAWS GOVERNING SOLUTES.

It has been found convenient in discussing solutions to introduce certain terms, and, as it will greatly simplify what is to follow, they are here defined. The substance in which the solution takes place is known as the *solvent*, and the substance which goes into solution in the solvent is called the *solute*.

From the study of the phenomena presented by solutions it has been very clearly shown that the solute is in a condition strictly analogous to a gas—that is, its molecules are perfectly free to move about among themselves within the limits of the solution. Just as the movement of the molecules of a gas results in a pressure on the walls of a containing vessel, so the movement of the molecules of a solute will result in a pressure on the walls of a containing vessel; only the medium in which they are free to move—the solvent—must extend beyond the walls of the vessel and be able to pass freely through them. Vessels with such walls have been realized; they have been filled with a solution, immersed in the solvent, and the pressure on the walls of the molecules of the solute—trying to diffuse into the outside solvent—has been measured quantitatively. This pressure, which has been called the *osmotic pressure* to distinguish it from the gas pressure known as *vapor pressure*, has been found to be actually the same in amount as the vapor pressure would be at the particular temperature, if the substance could be a gas at that temperature.

It has long been known that certain relationships hold between the volume, pressure, and temperature for all gases, irrespective of what

the particular nature of the gas may be. The explanation for this, which is universally accepted at the present time, is that in a gas the particles of which it is composed (the molecules, if the molecular constitution of matter be accepted) are possessed of such a large degree of freedom that they are entirely able to move about among each other without this motion being impeded by anything in the nature of the molecule itself—in its shape, size, or other property. This view is supported, for instance, by the fact that a gas will diffuse or spread out into space indefinitely (practically) if not confined in a retaining vessel, which neither a liquid nor a solid can do without first passing into the gaseous state; and by the further fact that when the volume is forcibly made small or the gas put under great pressure, whereby the molecules are forced together so that presumably the individual motions are affected by the peculiar nature of the molecules, the gas obeys the usual laws governing the volume—pressure—temperature relations less and less accurately. It follows that these volume—pressure—temperature relations are dependent only upon the *number* of molecules involved.

Just so a solute by virtue of the presence of the solvent is supposed to separate into molecules which can move so freely among one another as to be independent of any inherent characteristic of the molecule itself and, consequently, will move or diffuse throughout the solvent until the solution becomes homogeneous. Only, instead of diffusing indefinitely into space, the ultimate volume which the solute may occupy, independent of any containing vessel with semipermeable walls, is the volume of the solution. Therefore, it would be expected that these volume—pressure—temperature relations which hold for gases would also hold for solutes, as it is only the number of molecules of the solute which are involved in determining them and not anything in the nature of the molecule itself. This has been found to be the case exactly, and all the laws governing these relations for gases are also laws for solutes if we substitute the term osmotic pressure for the vapor pressure.

DISSOCIATION OF ELECTROLYTES.

The solutions with which we most commonly meet, and those which will almost exclusively interest us, are those in which the solvent is water and the solute or solutes are salts; that is, substances formed by the action of an acid on a base. These substances, when dissolved, show wide variations from the laws which have just been described. These variations are, perhaps, best studied by a consideration of the osmotic pressures they exert, which are found in all cases to be higher than was to be expected. Furthermore, these pressures vary with temperature or concentration in a way entirely different from solutions in general. It was first pointed out by Arrhenius that these variations are characteristic of solutions of electrolytes; that is, solutions in which the electric current passes. By making use of a hypothesis

which had been advanced by Clausius the phenomena were readily explicable. Clausius was led to assume that when an electrolyte was dissolved in water it separated, partially at least, into components or, as we now say, dissociates. These dissociated parts are chemical equivalents, and in the act of dissociating develop equivalent amounts of electricity with different signs. Thus sodium chlorid would dissociate into sodium, bearing a certain amount of electricity with the positive sign; and a chemically equivalent amount of chlorine, bearing an equal amount of negative electricity. In the notation of chemistry this is expressed
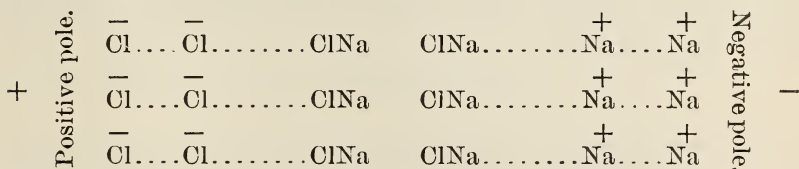
$$NaCl \gtrless \overset{+}{Na} + \overset{-}{Cl}$$
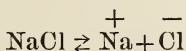
In an exactly similar manner sodium sulphate would dissociate as thus indicated:

$$Na_2SO_4 \gtrless \overset{+}{Na} + \overset{+}{Na} + \overset{-}{SO_4}$$
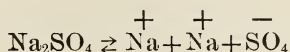
the negative electricity on the group SO_4, or sulphion exactly equaling the positive electricity on the two sodium equivalents.

Borrowing an expression introduced by Faraday, these dissociated parts *with their electric charges* are called *ions*. When the solution containing ions is put in an electric circuit, the ions bearing the positive charges are attracted to the negative pole of the circuit and the ions bearing the negative charges toward the positive pole, in accordance with the well known law of electricity.

Retaining sodium chlorid as an example, we may illustrate the phenomena by a mechanical analogy, thus:

| Positive pole.						Negative pole.
+	$\overset{-}{Cl}\ldots\overset{-}{Cl}\ldots\ldots ClNa$	$ClNa\ldots\ldots\overset{+}{Na}\ldots\overset{+}{Na}$				$-$
	$\overset{-}{Cl}\ldots\overset{-}{Cl}\ldots\ldots ClNa$	$ClNa\ldots\ldots\overset{+}{Na}\ldots\overset{+}{Na}$				
	$\overset{-}{Cl}\ldots\overset{-}{Cl}\ldots\ldots ClNa$	$ClNa\ldots\ldots\overset{+}{Na}\ldots\overset{+}{Na}$				

The chlorine ions on arriving at the positive pole give up their electric charges, thus becoming ordinary chlorine, which escapes as the well-known gas or reacts on the water of the solvent to form hydrochloric acid and oxygen, which escapes as a gas. In a similar manner the sodium ions discharge their electric burdens, thereby becoming ordinary sodium, and immediately react on the water to form sodium hydrate and hydrogen. It is to be observed, however, that the chemical behavior of the ions is entirely different from what it becomes when their electric charges have been lost. The illustration just used indicates that there would be a gradual accumulation of hydrochloric acid at the positive pole and of sodium hydrate at the negative pole. This is what actually happens, as anyone can readily test by drawing off portions of the solution near the poles and analyzing them.

Each of these ions in solution behaves to all intents and purposes as an individual molecule and exerts its influence as such in determining the osmotic pressure in the solution.

Without going into details, it may be said that from an estimation of the osmotic pressure it is possible to determine the number of ions in a given solution. From the conductivity it is also possible to determine the number of ions; and the agreement by both of these methods is of such a character as to make this idea of electrolytic dissociation or ionization one of the best established working hypotheses science now possesses.

REVERSIBLE REACTIONS AND THE MASS LAW.

Suppose a solution of a salt, for example sodium chlorid, be brought in contact with another salt, such as potassium nitrate. There will then be in the solution not only the sodium chlorid and the potassium nitrate, but the ions formed from them, which may be represented thus:

$$\overset{+}{\text{Na}}\text{Cl, KNO}_3, \overset{+}{\text{Na}}, \overset{+}{\text{K}}, \overset{-}{\text{Cl}}, \text{ and } \overset{-}{\text{NO}}_3.$$
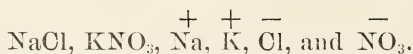
But the $\overset{+}{\text{Na}}$ ions and $\overset{-}{\text{NO}}_3$ ions can form sodium nitrate and will form it to a certain extent, so that we shall have this salt also in the solution. In the same way potassium chlorid will be formed and the final state of the solution will represent an equilibrium between the solvent water and the various salts and ions which can be formed. It is obvious that the same condition could be obtained by starting with sodium nitrate and potassium chlorid; and the equilibrium could be displaced one way or the other by varying any of the constituents. Such a reaction is called *reversible*. Again, sodium chlorid in water partially dissociates thus:

$$\text{NaCl} \leftrightarrows \overset{+}{\text{Na}}, \overset{-}{\text{Cl}}$$
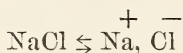
But if the concentration be altered by the addition or evaporation of water, the equilibrium is displaced and either more sodium chlorid will dissociate or more will be formed from the already dissociated ions. In fact, practically all simple reactions so far studied, whether in solution or otherwise, have been found to be reversible.

Suppose a reversible reaction between A and B with the formation of C and D. It may be expressed thus:

$$\text{A+B} \leftrightarrows \text{C+D}$$
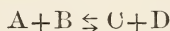
Let p, q, r, s represent the active masses or the number of molecules per unit volume acting, respectively.

Let K be the rate of combination of unit masses of A and B to form C and D, and

Let K_1 be the rate of combination of unit masses of C and D to form A and B.

The magnitude of the reaction $A+B \rightarrow$. is Kpq, for it is directly proportional to the rate of combination and to the active masses, and it will be K_1rs for the reaction $C+D \rightarrow$. Therefore when equilibrium is established

$$Kpq = K_1rs. \qquad (1)$$

This is known as the law of "mass action," or of Guldberg and Waage. It is conventional to take as the unit of active mass in solutions one reacting weight per liter.

Applying this formula to the case just cited,

$$NaCl \leftrightarrows \overset{-}{Na} + \overset{+}{Cl},$$
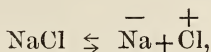
we would have

$$K_1pq = K_2r,$$

where p represents the concentration of the ion $\overset{-}{Na}$, q that of the ion $\overset{+}{Cl}$, and r that of the undissociated salt $NaCl$. From which

$$\frac{pq}{r} = \frac{K_2}{K_1} = K_i \qquad (2)$$

which is known as the dissociation or ionization constant, and is a constant for constant pressure and temperature, but is different for different salts.

For those acids and bases and their salts which are usually characterized as strong K_i is found to be large, while on the contrary it is always small for the so-called weak acids, bases, and their salts. Since it is obvious that it is the active masses of the ions which make an acid or base weak or strong, the magnitude of K_i is generally taken as the measure of the relative "strength" of an acid or base at the present time.

Still applying formula (2) to such a case as

$$NaCl \rightleftarrows \overset{-}{Na} + \overset{+}{Cl}$$
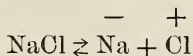
we see that for every $\overset{-}{Na}$ ion there will be a $\overset{+}{Cl}$ ion—that is, the concentration or active mass will be the same, and

$$\frac{p^2}{r} = K \text{ or } p^2 = Kr$$

therefore the concentration of the undissociated salt is proportional to the square of the concentration of the dissociated salt. From which it follows that the greater the dilution the greater the proportion of dissociated to undissociated salt.

HETEROGENEOUS EQUILIBRIA.

So far we have considered only cases of homogeneous equilibrium, where we had but one reversible reaction and complete solution. But there are certain types of heterogeneous equilibrium which remain to be considered.

Suppose a salt S in contact with a solution saturated with respect to it and containing therefore S^1 of it. S^1 will be partially dissociated into A and B.   Let c be the concentration of the undissolved salt, c_1 the concentration of the dissolved but undissociated salt, and a and b the concentrations, respectively, for the ions.   When equilibrium shall have been established between $S \rightleftarrows S^1$ the equation expressing the fact will be

$$\frac{c}{c_1} = K_1 \tag{3}$$

but c, the concentration of the undissolved substance, is the same thing as its specific gravity—that is, a constant K_2; therefore

$$c_1 = \frac{K_2}{K_1} = K_3 \tag{4}$$

From the dissolved salt we get $S^1 \rightleftarrows A + B$ and

$$\frac{ab}{c_1} = K_4 \tag{5}$$

from which, substituting from (4),

$$ab = K_3 K_4 \text{ or } K_s \tag{6}$$

which is known as the solubility constant.

If the equilibrium remain undisturbed, this equation (6) will hold, but if it be disturbed there will be two possibilities, either ab is greater than K (ab > K) or ab is less than K (ab < K).   If ab > K, then the reaction will go $A + B \rightarrow S^1$ and $S^1 \rightarrow S$, and there will be a precipitation of the salt.   If ab < K, the reaction will go $S \rightarrow S^1$ and $S^1 \rightarrow A + B$, and there will be a further solution of S.

If we have two or more salts brought into solution in water, as was indicated above, there will be formed also all the possible combinations of which the dissociated ions are capable, as well as the ions themselves, and of all these possible combinations that one will be the first to precipitate the product of whose ionic concentrations shall first exceed its solubility constant.   Suppose, for example, that to a solution containing sodium chlorid NaCl and its ions $\overset{+}{\text{Na}}$ and $\overset{-}{\text{Cl}}$ we add potassium chlorid which will yield its ions $\overset{+}{\text{K}}$ and $\overset{-}{\text{Cl}}$, one of which is common to the salt already in solution.   Then the product of the ionic concentrations of both salts is thereby increased.   It might happen that this product for the salt already in solution was equal to its solubility constant; the increase in the product brought about by the addition of the salt with a common ion will indicate a state of instable equilibrium; there will be a "forcing back of the dissociation" with formation of an excess of undissociated salt and its precipitation from the solution.   Thus lead chlorid can be easily precipitated from a solution by the addition of potassium chlorid.   By adding strong hydro-

chloric acid solution to a moderately concentrated solution of barium chlorid one can precipitate the latter in beautiful crystalline scales. A very interesting case, illustrating these views, which is to be found in nature, has recently come under investigation in this laboratory.

CARBONATES AND LIME IN GREAT SALT LAKE.

The water of the Great Salt Lake in Utah is a strong solution of salts. The most conspicuous base present is sodium, though there are also potassium, magnesium, and a small amount of calcium. There is reason to believe that strontium would be found on a careful examination, but it is present (if at all) in amounts which could easily escape detection without unusual refinement in the analysis. Among the acids present carbonic acid has not been recorded in any analysis of the water so far as I am aware. But its presence has been clearly shown by an examination in this laboratory. While working in the neighborhood of the lake recently it occurred to Mr. Gardner, of this division, to test the alkalinity of the lake water by adding a few drops of alcoholic phenolphthalein solution to a sample. No alkaline reaction could be observed, but on throwing away the tested sample and rinsing the containing vessel with distilled water a distinct pink color, denoting an alkaline reaction, was observed in the wash waters. An examination of the distilled water failed to show any alkalinity and the matter was referred to this laboratory. Samples of the water from the lake were examined and found to show no reaction with phenolphthalein, but on gradually diluting the solution the pink color appeared. Strong artificial brines of sodium chlorid were then prepared and small quantities of sodium carbonate added. These also failed to show any color on the addition of phenolphthalein, but yielded the color on dilution. The reverse experiment was then tried of gradually adding sodium chlorid to a solution containing a small amount of sodium carbonate and colored a strong pink with phenolphthalein. As the concentration of the solution with respect to the sodium chlorid increased, the color gradually disappeared. The explanation of the phenomena was clearly demonstrated. The small amount of carbonate present would be but little dissociated under any circumstances, the carbonates all having a very low ionization constant. But the very large number of sodium ions in the solution derived from great quantities of sodium chlorid and sulphate present, the solution, in fact, practically saturated with respect to them, forced back the dissociation of the weakly dissociating sodium carbonate until there was none of this salt ionized in the solution. Sodium carbonate itself is not capable of an alkaline reaction and its solutions only become so through its ionization products, as will be explained later. In consequence this delicate test for its presence of necessity failed, and the small amount of carbonic acid involved could be very readily overlooked in the analysis, especially when there

was no reason to expect its presence. It may be of interest to note that an examination in this laboratory has shown the amount of sodium carbonate present to be about 0.012 per cent of the solution.

The absence of more than a comparatively insignificant amount of lime from the waters of the lake has been the subject of much comment, especially as salt lakes in general contain a good deal of lime, sometimes even an astonishing amount. That calcium salts have been brought into the lake in very considerable quantities there is most abundant evidence in the large amounts of carbonate of lime found on the shores and bottom of the lake. But calcium carbonate could not remain in solution in the lake water to any greater extent than a mere trace, for it is a very slightly soluble substance in itself and could not be ionized, as we have just seen, since the conditions are impossible for the existence of any carbonic-acid ions. Moreover, the water of the lake contains so much sulphate in solution that it must be regarded as practically saturated with respect to sulphions. Therefore only so much calcium sulphate can remain in solution as will be soluble without ionization—a comparatively small amount, as is well known. Should there be other calcium salts in the solution they would be continually dissociating and forming calcium sulphate and being precipitated from the solution until equilibrium should be restored. It should be remembered, however, that the soluble carbonates constantly being brought into the lake will tend to restore the sulphions to the solution, the carbonic-acid ions going out of solution with the lime. Nevertheless, it is the relatively large amount of sulphates of the alkalis present which must be regarded as the controlling factor in the small amount of lime soluble in the waters of the lake.

### TWO OR MORE SOLUTES WITH NO COMMON ION.

Suppose, on the other hand, that to a solution containing an electrolyte another containing no common ion be added. As has been already illustrated, there will be at once the formation of all the combinations possible to the ions, and with the consequent taking away of the ions for this purpose there will be a lowering of the product of ionic concentration for each of the salts; that is, the solubility will be increased. This phenomenon is most strikingly illustrated in the case of those salts usually regarded as insoluble. For instance, gypsum, which is essentially the salt calcium sulphate containing some water, is sparingly soluble in water. But the addition of an electrolyte with no common ion, such as sodium chlorid, will considerably increase the solubility of the gypsum. Some experiments made in this laboratory have shown that in moderately strong brines containing only sodium chlorid gypsum can be regarded as a soluble salt. The reason for this is readily seen when the substances which are formed are considered, both the calcium chlorid and the sodium sulphate being very soluble salts. The transportation of large quantities of lime by the drainage and

ground waters in arid regions where these salts are found is readily explicable from this point of view.

Calcium carbonate, so abundant and so important in nature, is dissolved in a precisely similar way; but the ionization of carbonates being relatively small, the effect is not so striking and relatively much less lime is transported in the solution. Treadwell and Reuter[1] have recently published investigations on this point and find the solubility of calcium carbonate in sodium chlorid solutions does not become markedly large until considerable concentrations of the latter salt are reached. The effect of carbon dioxid in forming the more soluble bicarbonate of lime undoubtedly is an important element in this connection, but as the ionization is but little affected by its presence its influence must be small in the presence of such a salt as sodium chlorid.

HYDROLYSIS.

Water is itself a very weak acid with a very low ionization constant, but it does dissociate to a limited extent into hydrogen and hydroxyl ions, thus:

$$H_2O \rightleftarrows \overset{+}{H} + \overset{-}{OH}.$$
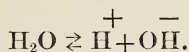
The absolute amount of this dissociation is very small, but it has been the subject of the most careful and painstaking investigation. From the work of Kohlrausch, Ostwald, Arrhenius, and Weis it would appear that absolutely pure water would contain certainly less than 1 gram of hydrogen ions in 12,000,000 liters of water, but nevertheless there would always be some present. These dissociated ions from water will of course react with the ions of the dissolved electrolyte, thus:

$$NaCl + HOH \rightleftarrows NaOH + HCl,$$
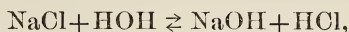
but the ionization constants of the sodium hydrate and the hydrochloric acid are very large, while that of water is relatively very small indeed, so that the latter will be formed and precipitated as such nearly completely, and the total effect will be so small as to be incapable of detection by ordinary methods. This will be true for any electrolyte with high ionization constant, but with an electrolyte which ionizes to a small degree the effect becomes important. For instance, sodium carbonate has a very low ionization constant in water. The reaction is indicated thus:

$$Na_2CO_3 + HOH \rightleftarrows Na\,OH + HNaCO_3,$$
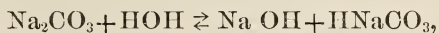
and while the acid sodium carbonate does dissociate further it is to a very slight extent, as is the dissociation of the sodium carbonate and water as compared with the dissociation or ionization of the sodium hydrate; in consequence, the solution behaves as though it were, as in

[1] Zeit. Anorg. Chem., **17**; 170 (1898).

fact it is, a solution of sodium hydroxid. This phenomenon of the dissociation of the salt of a weak acid or a weak base in water, with the formation of the corresponding strong base or acid possible, has been called *hydrolization*. The ionization of water is increased by heating, a fact of importance in many analytical operations. It can be very beautifully illustrated with calcium carbonate. If powdered marble be shaken up with water it dissolves to a very slight extent and is hydrolized with the formation of calcium hydrate, which can be shown by the alkaline reaction with a few drops of phenolphthalein. On heating the color becomes very greatly intensified, but on cooling it gradually returns to its former condition. This increased hydrolytic power of heated waters is obviously of the first importance in studying geological problems involving the solution of such weak salts as carbonates, silicates, aluminates, borates, etc., but its full significance can hardly be said to be appreciated as yet.

HILGARD ON THE RÔLE OF CARBON DIOXID.

The importance of these relations in studying soil conditions and drainage waters, especially in arid regions where soluble salts abound, has not been without some recognition. Hilgard, with Weber,[1] and later with Jaffa,[2] has given the subject a good deal of attention and has formulated an hypothesis to account for facts observed. The importance of the subject and the authority which attaches to the views of this investigator both call for a somewhat detailed examination of the hypothesis.

From long observation Hilgard was impressed by the very great frequency of the occurrence of gypsum in alkaline waters and soil leachings, even when considerable quantities of soluble alkaline carbonates were present and when, a priori, the precipitation of all (practically) of the calcium in the gypsum as insoluble calcium carbonate might be expected.

On looking over the literature he found a few sporadic references pertaining to the subject, wherein no explanation is advanced, or the phenomena are ascribed to some peculiar solvent action of the salts, without, however, any hypothesis as to the nature of this reaction.

These solutions containing the gypsum or in contact with it are always alkaline, but on being evaporated to dryness or to relatively high concentration, this alkalinity is diminished and a greater or less amount of the calcium of the gypsum is precipitated as the ordinary carbonate.

Considering the origin of these solutions, Hilgard is led to the view that the unlooked-for phenomena presented are due to the presence of an excess of carbonic acid in the waters or soil leachings, and points

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[1] Proceedings of the Society for the Promotion of Agricultural Science, 1888, p. 40.
[2] Ibid, 1890, p. 80.

out the great probability of its presence. This view was tested by passing carbon dioxid, for various periods of time from ten minutes to two hours, into solutions of alkaline sulphates and chlorids, at the ordinary room temperature, in which precipitated calcium carbonate was suspended. Taking care to avoid the first masking of the reaction, which sometimes occurred from the large excess of carbon dioxid, in all cases the solutions were found to have become alkaline and, on the addition of alcohol to the solution, a precipitate was thrown down in which gypsum and calcium carbonate could both be readily recognized.

Together with Weber he then undertook some quantitative measurements. He made up solutions containing from 0.25 grams to 2 grams potassium sulphate per liter. In these solutions he suspended calcium carbonate and kept the solutions agitated while passing in carbon dioxid for 40 minutes. The solutions were kept at 18° during the experiment and a little litmus was added. At first the solution would redden, owing to the action of the carbonic acid on the litmus, but in about ten minutes it would become blue, the color intensifying as the reaction progressed. At the end, aliquot portions were filtered and tested as follows: .

I. The " total alkalinity" was determined by titrating with normal sulphuric acid (alkalinity = No. of cc's of the normal acid required).

II. The portion was completely evaporated and dried at 110°, then leached, and the alkalinity of the leachings determined by titration with normal sulphuric acid.

III. To this portion alcohol was added to make about a 60 per cent alcohol solution, whereupon a gelatinous precipitate settled, which, after twelve hours' standing, had separated into easily recognized crystals of gypsum and calcium carbonate.

From the figures obtained it was concluded that to a point somewhere between the solutions containing one-half gram and 1 gram per liter of potassium sulphate the reaction was complete as to the replacement of the sulphion by the $\overline{CO_3}$-ion, but beyond this the replacement was less complete and the relative amount of the replacement was a regular function of the initial concentration; further, that the solutions did not necessarily become saturated with respect to acid calcium carbonate, or the composition of the residue affect the alkalinity.

The further discussion by Hilgard, while interesting in itself, is not important for our purposes, and the examination of his views may fairly be undertaken with this statement of them.

It should be remembered that calcium carbonate is itself soluble to some extent and hydrolized, as has been indicated on page 18, thus:

$$CaCO_3 + HOH \rightleftarrows Ca(OH)_2 + CaH_2(CO_3)_2$$
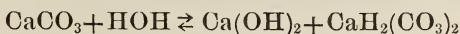
and the solution behaves as a very weak solution of the calcium hydrate, itself but a slightly soluble substance, but distinctly alkaline toward indicators.

When the potassium sulphate is brought into the solution, the solubility of the calcium carbonate is materially increased, since the amount of the calcium that can be held in solution as calcium sulphate is decidedly greater, and the equivalent amount of carbonic acid is now in the form of the very soluble salt, potassium carbonate, thus:

$$K_2SO_4 + CaCO_3 \rightleftarrows K_2CO_3 + CaSO_4$$
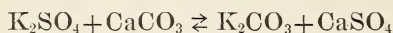
and the potassium carbonate formed being at once hydrolized for the reasons already given,

$$K_2CO_3 + HOH \rightleftarrows HKCO_3 + KOH,$$
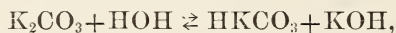
whereby we have the very soluble and highly ionized potassium hydrate and a characteristic strong alkaline reaction.

It should be borne in mind in experimenting that even with the most finely divided calcium carbonate some little time is required for the solution to come to equilibrium and this full effect to become observable.

If carbon dioxid be now passed into the solution, that is to say, carbonic acid be dissolved therein, at least two effects must be considered. It will tend to decrease the solubility of both the calcium carbonate and the potassium carbonate by driving back the dissociation, supposing, of course, that it is present in excess. But as the dissociation of these salts is very small, this effect of its presence will not be appreciable, for its other result will be the formation of bicarbonate of both calcium and potassium, thereby increasing the solubility of the calcium and increasing the amount of this metal in the solution. The potassium bicarbonate is less soluble than the carbonate, but both salts are so soluble that this is no factor in the case before us.

In spite of a widespread impression to the contrary, acid potassium carbonate has been clearly shown to be neutral and not alkaline in its reaction. This fact has been confirmed and most clearly demonstrated by recent work in this laboratory. But it has also been shown that it is a very instable compound, especially when in solution, quickly inverting with the formation of the normal alkaline carbonate, even though some carbon dioxide must be present. It is this inverted normal carbonate which in turn is hydrolized with the formation of potassium hydrate, which gives the solution its alkalinity.

The solution, after the treatment described, will then contain calcium sulphate, potassium sulphate, calcium carbonate or bicarbonate, potassium bicarbonate, and potassium carbonate hydrolized, and these constituents are in such proportions that stable equilibrium exists. As evaporation proceeds this equilibrium is disturbed and the relative proportions vary, accompanied finally with successive separations of these various salts in the solid form. But always, up to complete desiccation, there will theoretically, at least, be *some* of each of these salts in the solution in equilibrium with the others, though the absolute amount of any of them may, and undoubtedly for some will, become quite small.

The addition of alcohol to the solution, by decreasing the solubility of some of the constituents, or all of them, will produce analogous results, differing only in the quantitative relations to one another. Thus the solution, it is obvious, must remain alkaline. After desiccation resolution would restore the original conditions for the same total concentration, if other things were equal. But it seems probable, from what we now know, that the solubility of the gypsum is materially affected by drying at 110°, and undoubtedly the acid potassium carbonate would be, which facts are quite competent to account for Hilgard's results with the leached residues.

It will be shown later that the method he used for determining the alkalinity of his solutions gives misleading results, and his conclusions derived therefrom cannot fairly be given more than a qualitative value. The main thesis of the paper, that the carbon dioxid dissolved in the soil and other natural waters is the controlling factor, at least in the sense he means it must be regarded as incorrect. The observed phenomena are readily accounted for in a much more complete way in terms of the conventional theory of solutions, and the presence of the carbon dioxid is an unnecessary, though contributing, cause for the observed phenomena.

GYPSUM AND AMMONIUM SALTS.

It seems pertinent here to call attention to another reaction which has a widespread application. When ammonium carbonate and gypsum are brought into contact we may indicate the reaction that takes place thus:

$$(NH_4)_2CO_3 + CaSO_4 \rightleftarrows CaCO_3 + (NH_4)_2SO_4,$$
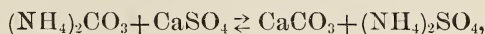
calcium carbonate and ammonium sulphate being formed. This fact is made of use for the preservation of ammonia salts in manure piles by the application of gypsum and, under the conditions that there exist, the reaction probably "runs to an end;" that is, all the calcium is converted into the carbonate. The same reaction results may be assumed for the bicarbonate of ammonium. Unlike the corresponding sodium and potassium salts, ammonium carbonate is quite instable. In water solution it immediately commences to break down, forming the acid or bicarbonate. This transformation is greatly accelerated by heat.

The experiment was made in this laboratory of boiling a solution of ammonium carbonate for about twenty-five minutes, in contact with an excess of pure pulverized gypsum. The solution was then allowed to cool and settle. A major portion of the clear supernatant liquid was evaporated until crystallization. The crystalline mass was identified as ammonium sulphate, and on platinum almost completely volatilized when heated, a very small residue being left which could be recognized as a calcium compound by the flame test.

As some of the ammonium sulphate must always remain in the solution, even to complete dryness, it is obvious that the use of ammonium carbonate solution for the reconversion to carbonates of the alkaline

earths after ignition, is not permissible when the soil contains gypsum or similar compounds. In spite of a warning by Hilgard[1] this fact is not always recognized and has been the occasion of some annoying experiences.

AMELIORATION OF BLACK ALKALI.

The amelioration of the conditions when "black alkali" exists is a subject for grave consideration. A suggestion has been made by Hilgard which has been found to have great value. It is to apply gypsum or land plaster to the soil containing sodium carbonate. The reaction takes place as here indicated:

$$Na_2CO_3 + CaSO_4 \rightleftarrows CaCO_3 + Na_2SO_4,$$
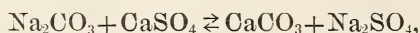
the noxious sodium carbonate being to a greater or less extent converted to less harmful sodium sulphate or "white alkali" and the harmless and but slightly soluble carbonate of lime. The solubility of the calcium carbonate being so very small and made even less so by the presence of the more soluble calcium sulphate with a common ion, the tendency of the reaction will be to "run to the end" before equilibrium is established. But to bring about this desired result it is necessary that the soil should be well drained and aerated, partly, in order to carry off the soluble salts; and this may well be of considerable importance, for there is evidence for the opinion that soils show a selective absorption or adsorption, and recent work of Mr. L. J. Briggs, of this division, indicates that sodium sulphate is much more readily leached from a soil than sodium carbonate. But more especially because in the presence of water and in a soil which is not well aerated there exists a condition favorable to the conserving of carbonic acid in the soil and, under the influence of this agent, the calcium carbonate is converted into the acid carbonate, its solubility much increased, and therefore its active mass, with the result that a reaction opposite to the one just indicated will prevail. Thus

$$CaCO_3 + H_2CO_3 \rightleftarrows CaH_2(CO_3)_2,$$

and

$$Na_2SO_4 + CaH_2(CO_3)_2 \rightleftarrows CaSO_4 + NaHCO_3,$$
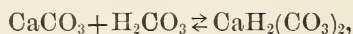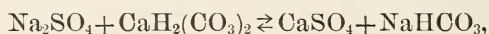
but the acid sodium carbonate formed, as will be shown, is instable in solution and at once inverts with the formation of the undesirable sodium carbonate, even when some carbonic acid must be present.

$$NaHCO_3 \rightleftarrows Na_2CO_3 + H_2O + CO_2$$

Empirically these controlling conditions were determined, and pointed out by Hilgard. A correct understanding of their influence and importance must prove of use in their management.

[1] Loc. cit., 1888, p. 40.

ANALYTICAL PROBLEMS.

The preparation of a sample of soil or soil crust containing large amounts of these soluble salts presents peculiar difficulties. The problem is not the complete chemical analysis of the specimens. This would but require the easy application of familiar conventional methods. What is desired is information as to the portion of the sample which is soluble in water. The total amount present in solution in water in contact with the soil can be determined in such cases where it may be desired by the investigator in the field, with altogether sufficient accuracy, by means of the well-known electrical instrument designed in this division. The question to be answered in the laboratory is what salts are present and their relative proportions in these soil solutions.

The sample, as it comes to the analyst, is usually a dried portion of the soil or soil crust. Since the total amount of salts present is not desired, any convenient amount may be taken for the analysis. Two modes of procedure suggest themselves:

I. To leach out the soluble constituents. Experience has shown this to be an ineffective method. It has been known since Bronner's work, in 1836, confirmed by the work in Liebig's laboratory, that of Way, and many others since, that soils are peculiarly adapted to the illustration of the little understood phenomena of selective adsorption and absorption. Some little attention has been given to this subject in recent years, principally by Ostwald. But it must be said in all frankness that our knowledge of the matter is in a very unsatisfactory state. Attempts were made to extract some of these soil crusts by throwing them on a filter and extracting with successive portions of water.

The mechanical difficulties in the filtering, the inefficiency of the method, as evidenced by the very considerable amounts of chlorid in the wash water after many extractions, caused this procedure to be abandoned. Some of the same soil crusts were then put in a continuous extraction apparatus which was known to be of a very efficient type. After extraction for three working days of eight hours, it was found that there were yet very large quantities of chlorid in the crust. After seven days' extraction chlorids were still coming through. Considering the nature of the salts present, an application of the laws of solution seemed to cast doubt on the validity of this method, aside from the difficulties just described, so that it has been definitely abandoned in this laboratory. It would seem desirable that a more systematic and careful investigation of the matter should be made, and it is hoped that the subject will appeal to some one whose time and opportunities will permit it.

II. The procedure we follow at present is to take about 20 grams of the sample, if it appears to be largely soil, more or less according to judgment as the proportion of salts varies, and shake up thoroughly

with about 350 cc. of water. This shaking or stirring is repeated frequently for a day. The whole is then allowed to stand overnight, or a day, as convenience dictates. The supernatant liquid, which is usually quite clear, is then decanted through a filter, as much as possible being poured from the residual mud without actually draining it. The filtrate is then made up to about 500 cc. and aliquot portions taken for the analysis according to the conventional method. Certain assumptions are made in this procedure, but they appear warrantable. It is to be supposed that some of all the salts remain in the residual mud. Gypsum, which is a very common constituent in these samples, undoubtedly fails to be extracted to anything like completeness. Moreover, the solution which is decanted from the soil may well be quite different in concentration from the solutions which would occur in the field, and consequently the proportion of salts dissolved may be different from the larger volume of water used. Taking these facts into consideration, it nevertheless seems probable that the solution as we prepare it gives a *fair approximation* to the soluble constituents of the soil, barring, of course, excessive amounts of such a substance as gypsum, and will give a fair idea of what a drainage water in that soil would carry away. We can only say that in the light of our experience, and after giving a great deal of consideration to the subject, it seems to present fewer objections than any procedure so far suggested.

It sometimes happens that after decanting through the filter the solution will remain more or less cloudy, even after prolonged standing. When cloudiness is due to suspended mineral matter, it can generally be removed by running the solution a second time through a Schleicher and Schüll "hardened" filter, drying the filter, and washing as quickly as possible with several successive small portions of hot water.

In general what the analyst has to estimate in the solution are the chlorids, sulphates, and carbonates of calcium, magnesium, and sodium. Occasionally other substances, as the salts of potassium and strontium, may be present in sufficient quantity to require their estimation, but this is exceptional; usually they are present in such minute quantities that they may be disregarded. Too little is known, as yet, regarding the nature of the organic matter which may be in the solution, and its effect on the other constituents to make its determination of any value. It is important, however, that a *direct determination* of all the constituents usually found should be made, and it can not be assumed that any one of them, the sodium for instance, can be calculated by difference. If there be organic matter in the solution, an attempt to determine the total mineral constituents will necessitate its burning at a temperature which will inevitably cause a loss in the other constituents. Its oxidation by other methods, while possible, is not justified on account of the time required, and, moreover, either liberates the carbonic acid or presents other chemical objections. The difficulty in

exactly dehydrating a residue, when there will be so much "water of crystallization," will be sufficiently obvious to any analyst. To attempt to calculate the amount of sodium required with the other bases to exactly neutralize the acid found will often yield misleading results where there are mixtures of monovalent and bivalent acids. Under such circumstances different analysts would get different results, depending upon the way in which the various bases and acids were combined.

The statement of the analytical results merits attention. The conventional method of stating them as salts is often misleading and generally quite unwarrantable, with our present knowledge. To illustrate, the writer had occasion recently to compare the analyses of the mineral constituents of the Great Salt Lake, made through a wide range of time. The analyses were all calculated in the same way, presumably for purposes of comparison, and are stated thus:

	Gale, 1850.	Allen, 1869.	Bassett, 1873.	Talmage.	
				1885.	1889.
Sodium chlorid...........................	20. 20	11. 86	8. 85	13. 586	15. 743
Sodium sulphate	1. 83	.93	1. 09	1. 421	1. 050
Magnesium chlorid	.25	1. 49	1. 19	1. 129	2. 011
Calcium sulphate	....	.09	.20	.148	.279
Potassium sulphate	....	.53	....	.432	.474
Potassium chlorid	....	....	1. 89	....	....
Excess of chlorine	....	.09	.20	....	....
Total..	22. 28	14. 99	13. 42	16. 716	19. 557

Now the chlorine uncombined, stated in several of these analyses, can all be accounted for by recombining the data in a different way than that stated. It is not necessary to go into the details, as it is obviously a matter of mere arithmetical jugglery. It will be observed that all the magnesium is stated as having been present as chlorid, whereas it is probable that many other analysts, perhaps the majority, would have calculated it as sulphate. As to which would have been the better way there can be no dispute. By referring to the discussion in the earlier part of this paper it will be seen that as a matter of fact there must necessarily have been both magnesium chlorid and magnesium sulphate in the solution. In just what proportions they would be it is of course possible to say theoretically, but the practical difficulties in determining this question, in the vast majority of cases, may be regarded as at present entirely too difficult to warrant any attempt to do so. In view of the fact that it is the ions with which we really have to deal in the majority of instances, and that it is in fact the amount of the possible ions which may be formed that we actually estimate in our analyses, it would seem that the time has come when some institution or organization that could speak with authority should inaugurate the convention of stating analyses in this more rational way. The difficulties besetting any individual or sporadic attempts in this direction

are so patent they need no discussion. Yet the need of this reform for an intelligent appreciation and use of the material can not be too strongly urged.

Since the epoch-making work of Liebig there has been a constant effort on the part of chemists to determine the agricultural value of a soil by a chemical examination or analysis. The methods which have been suggested all depend upon the principle of bringing the constituents of the soil into solution to a greater or less extent in the presence of some acid.

The constituents of the soil are for the most part salts. These salts are in general but slightly soluble, it is true, but nevertheless soluble to some extent; and consequently in aqueous solutions would be ionized as other salts are, or, since they are usually salts of weak acids, hydrolized, as has been described elsewhere in this paper. The presence of an acid, or, for that matter, any other electrolyte, such as a base or a salt, displaces the equilibrium and alters the solubility of the soil constituents. Acids have met with most favor in this regard, and the reason for this is now apparent, because in dissociating they do not furnish ions common to the dissociating soil constituents, and hence the solubility changes are more marked when they are employed.

It will be readily seen that these acid extracts represent a state of equilibrium between the dissociated and undissociated electrolytes contained in the solution. If the acid solution be allowed to remain long enough in contact with the soil, it will become saturated with respect to the soil constituents or their ions if they are present in sufficient quantity, or will completely dissolve such of these constituents as are not present in sufficient quantity to saturate the solvent with respect to them; but with salts such as compose the soil the surface exposed as controlling the "active mass," as well as their comparatively small solubility, must be considered, and for a final complete state of equilibrium to be obtained will require generally that the solvent be kept in contact with the soil for a relatively long time.

It is obvious that in any particular case many factors or conditions enter, and the subject is bewilderingly complex. The temperature as controlling the solubility of the various electrolytes themselves; as controlling the migration velocities of the ions; the concentration of these various electrolytes and their resulting ions; their mutual effect in retarding or increasing solution when they yield a common ion or do not yield a common ion; the surface exposed and the time which it is exposed, must all be considered.

It is not surprising, therefore, that experience has shown different acids to have yielded widely varying results; that the same acid would not always yield comparable results, even when the same concentration was used, for in such a case the factors, common ions, and active mass are incontrollable. The practice finding most favor at the present day is to extract the soil with a hot concentrated aqueous solu-

tion of hydrochloric acid, but to this procedure there is the objection that the concentration with respect to hydrochloric acid, and therefore the active mass of this reagent, is measurably dependent upon the barometric pressure.

The conditions which will determine the equilibria in our acid extracts are similar in kind to those which control the equilibria of our soil solutions, but they are so utterly incomparable in degree as to make any attempt at formulating a quantitative comparison well-nigh hopeless. And when we consider the effect of other phenomena which are known to come into play in the soil, such as absorption or selective absorption, for instance, this attempt must be regarded as absolutely hopeless until we shall have obtained much more and precise knowledge regarding these subjects.

FIELD METHOD FOR ESTIMATING SULPHATES, CHLORIDS, AND CARBONATES.

It has often been found desirable in our field work to obtain a knowledge of the relative quantities of the various salts which may be present. Reference of samples to the laboratory for analysis by the regular methods is not practicable, on account of the time involved, it being necessary that the desired information be obtainable within a few hours at the furthest, in order to determine the direction in which the work in hand should proceed. To meet these requirements the following scheme has been devised:

The apparatus has been reduced to a minimum; it has been so arranged that it can be readily carried into the field, and our parties are regularly provided with a small carrying case, in which everything needful in the analysis is securely and neatly packed. It is provided with four or five burettes of 25 cc. capacity, graduated to $\frac{1}{10}$ cc. ($\frac{1}{5}$ cc. will answer every purpose quite as well); several bottles (generally four) holding 250 cc. when filled to mark on the neck; specimen vials and small bottles, to carry reagents—the solid reagents required for the standard solutions are carefully weighed into specimen vials or tubes in the laboratory, and sent out as required, the solutions being made in the field by means of the 250 cc. bottles mentioned; a small porcelain casserole, in which the titrations are made, and which can be heated over any fire— sometimes small Erlenmeyer flasks and a spirit lamp are preferred; and several clamps for fastening the burettes to the side of a wagon.

It is obviously impossible to provide a complete analysis under the conditions prescribed, but for the purpose desired it is sufficient to know the relative amounts of carbonates, sulphates, and chlorids present. Therefore the method is designed to estimate these acids, which for convenience are conventionally expressed in terms of the sodium salt. A sample of water is taken, or an extract is made from the soil, and the solution filtered or decanted. The solution need not be clear.

A known amount of barium nitrate is added in excess to 10 cc. of the salt extract, to precipitate sulphates and carbonates. The excess of barium nitrate is titrated back with a solution of potassium chromate, using silver nitrate on a porcelain tile or plate as an indicator. In the same vessel standard silver nitrate is run in to precipitate the chlorid, using potassium chromate on the porcelain plate as an indicator. A few drops of nitric acid are added, and the liquid heated to boiling, to drive off the carbon dioxid precipitated with the barium. The excess of nitric acid is neutralized with powdered magnesium carbonate. Again the solution is titrated with potassium chromate, the quantity required indicating the amount of carbonate in the original solution. This, subtracted from the amount required for sulphates and carbonates, indicates the sulphates present in the solution. The three titrations are all made in the one vessel, making the method a very rapid and comparatively simple one.

The method is not without its shortcomings, but it is in the nature of things intended only to obtain approximate results and has proven itself well adapted to this purpose. It may well be capable of refinement.

It should be noted that the estimation of the barium by adding potassium chromate, using the silver nitrate as an indicator, can not be advantageously done by adding the silver nitrate to the solution, and even on the porcelain plate the reaction is not all that could be desired. The presence of a chlorid in the drop taken for the test necessarily masks the reaction under observation, and even in the absence of chlorids the reaction is not "sharp."

The writer is indebted to Prof. J. D. Tinsley, of New Mexico, for assistance in testing this method, with a view to modifying it for laboratory practice. Without going into details, it may be said at once that the reaction does not appear well adapted to such an application of it. Its use in the field method just described is, however, warranted, considering the nature of the results desired. The scheme, as described, has been found of service for the purposes for which it was designed.

ESTIMATION OF CARBONATES AND BICARBONATES: A FIELD METHOD.

In the course of their survey work in the regions where the "black alkali" exists, our field parties felt the necessity of a rapid method for the estimation of the soluble carbonates in the soil, or really the alkalinity of the soil. They tried at first to meet this want by taking a standard volume of the soil, shaking it up with water and titrating with a standard acid. The results were very soon found to be valueless and the problem was referred to this laboratory as urgent. Obviously, the first thing to do was to study the reaction between an acid and sodium carbonate. It was very soon found that while very good concordant results could be obtained by heating to boiling the solution of sodium carbonate before titrating with standard sulphuric acid solution, that

such was far from the case when working in the cold. It ultimately developed that the formation of the acid carbonate or bicarbonate of soda from the liberated carbonic acid was the cause of the trouble. This salt, in spite of a widespread impression to the contrary, is perfectly neutral toward the usual indicators, but is very instable, and inverts readily to a greater or less extent, depending on the conditions, to the normal carbonate which is alkaline in water solutions. In titrating, therefore, with a standard acid solution widely varying results have been obtained, depending upon the rate at which the solution was run in, the temperature, etc.

In order to test this reaction more thoroughly a solution of sodium carbonate was prepared. Fifty cc. of this solution, treated with an excess of barium chlorid solution, gave 0.4840 grams of barium carbonate, equivalent to 0.2601 grams of sodium carbonate. Therefore, 1 cc. of the solution contained 0.005202 grams of sodium carbonate, while a tenth normal (N/10) solution should contain 0.00528 grams of the salt. A solution of sulphuric acid was made up and, after a number of preliminary trials to obtain concordant results—without success—a titration was made in the usual manner, using phenolphthalein as the indicator and titrating to loss of color, the solution being run in from the burette fairly rapidly. 10 cc. of the sodium carbonate solution was equivalent to 1.38 cc. of the acid solution.

Therefore,

1 cc. of the H_2SO_4 solution was equivalent to 7.2 cc. of the Na_2CO_3 solution, and

7.2 cc. of the Na_2CO_3 solution was equal to 0.0374 grams of sodium carbonate.

If the reaction is to be represented thus:

$$Na_2CO_3 + H_2SO_4 = Na_2SO_4 + H_2CO_3,$$
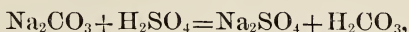
then 0.0374 grams of sodium carbonate should be equivalent to 0.03456 grams of sulphuric acid.

If the reaction is to be represented thus:

$$2\ Na_2CO_3 + H_2SO_4 = 2\ NaHCO_3 + Na_2SO_4,$$
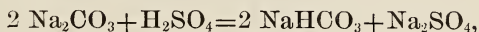
then 0.0374 grams of sodium carbonate should be equivalent to 0.01728 grams of sulphuric acid.

But 50 cc. of the sulphuric acid solution yielded 2.3345 grams of barium sulphate, therefore

1 cc. representing 0.0374 grams sodium carbonate was equivalent to 0.0196 grams of sulphuric acid.

From these results it was concluded that both reactions took place in this case, the latter predominating. Similar results, but different in the quantitative relations, confirmed this general conclusion. The method was therefore abandoned. Various methods were then tried and the

literature thoroughly scanned without finding anything suited to our purpose. Ultimately the following reaction suggested itself:

$$Na_2CO_3 + HKSO_4 = NaHCO_3 + NaKSO_4.$$
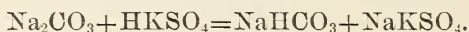
Acid potassium sulphate is a well-characterized acid, while both the reaction products are neutral. A tenth normal ($N/10$) solution of the acid potassium sulphate was prepared and titrated against the sodium carbonate solution, already described, using phenolphthalein as the indicator. 10 cc. of the sodium carbonate solution required 9.9 cc. of the acid potassium in solution, and this result was obtained time and again, only on standing the solutions gradually regained their pink color, due to the inversion of the acid sodium carbonate with the formation of the sodium carbonate. While this inversion commences almost at once, it is not rapid enough to interfere with the titration. This point will be referred to again later in this discussion.

It was proved that the reaction takes place as indicated with quantitative exactness. The reagent employed is one which can be readily obtained in any desired purity, and is very easy to handle. It remained to test it for field conditions. A solution of sodium carbonate was prepared, 10 cc. of which was equivalent to 13.5 cc. of the acid potassium sulphate solution. 50 cc. of this sodium carbonate solution and 10 grams of a loamy soil were put in a 500 cc. measuring flask, water added to the mark, and the whole vigorously shaken for several minutes. The solution was then allowed to stand and the soil to partially settle for five minutes. 100 cc. of the solution was then drawn out with a pipette, phenolphthalein solution added, and the turbid solution quickly titrated with the acid potassium sulphate solution, requiring 13.5 cc. This experiment was repeated with identical results.

In order to test the effect of sodium bicarbonate, if present in the soil, as we had reason to suspect was sometimes the case, a solution of this salt was prepared. It partially inverted, and blanks made with it showed that 10 cc. of the solution was equivalent to 0.8 cc. of acid potassium sulphate solution. Ten cubic centimeters of this solution were added to each of two 100 cc. portions of the muddy solution containing sodium carbonate, just described, and they were both titrated at once. They required 14.1 cc. and 14.2 cc. of the acid potassium sulphate solution, respectively, or, subtracting the correction, 0.8 cc. for the bicarbonate, 13.3 cc. and 13.4 cc. Therefore, it may be assumed that the presence of an initial amount of bicarbonate does not affect the reaction materially.

In order to test the method for field use a strong alkali soil, known to contain considerable sodium carbonate, was exactly saturated with water—a process capable of great precision in the amount of water used. Two portions of 20 grams each of the saturated soil, which we will designate as A and A[1], were washed into 500 cc. measuring flasks, water added to mark, and the whole vigorously shaken. They were

allowed to stand just five minutes to settle somewhat, and then 100 cc. portions were drawn off with a pipette for titration. The whole process was then repeated with fresh samples of this same soil, which we will designate as B and C. The number of cubic centimeters of a $\frac{N}{10}$ HKSO$_4$ solution required are here given:

A.		A'.	B.	C.
	49.1	50.3	49.1	45.8
	48.8	50.0	48.0	50.9
	48.6	49.2	49.0	46.3
	48.7	49.2	48.8	48.7
Average.	48.8	49.7	48.7	47.9

Under the conditions of the experiment these results may be regarded as quite satisfactory. They were determined by two observers indiscriminately and as a first test of the method. The particular soil chosen was one which gave a dark gray mud whose color made the end of the titration unusually difficult to determine, and, finally, all these determinations were made in a very bad light. Efforts were next directed to perfecting the mechanical details for field use. It may be said at once that the method has received a most rigid testing in the field as well as in the laboratory, and on solutions of known strength as well as on unknown soils, and has been found to be of easy application and very accurate. In the absence of any very unusual special condition there is no difficulty to titrating accurately to within 0.1 cc. of the N/10 acid potassium sulphate solution. This would correspond to 0.000528 grams of sodium carbonate. Supposing we started with 20 grams of saturated soil containing 15 grams of solid constitutents and made up the solution to 500 cc., titrating with 100 cc. portions, this would mean an error of 0.017 of 1 per cent. In soils containing from 0.5 per cent to 4 per cent of sodium carbonate this is an accuracy far beyond field requirements. In this laboratory the method is always used in the examination of alkaline soils and waters, and of course with the greatest accuracy that the circumstances will justify. It possesses the inestimable value of showing at once just how much of the sodium carbonate is present as the normal salt, capable of being hydrolized, and acting as an alkali. For this purpose, the usual method of titrating with a standard sulphuric acid solution or of estimating the sodium or carbon dioxid can only be regarded as entirely inadequate and misleading.

The apparatus and procedure finally adopted for the use of our field parties is as follows:

Several (usually four) glass bottles of convenient shape, with cork stoppers, of such a size as to hold 250 cc. of water at 20° C. when filled to a mark on the neck; one or more 25 cc. burettes, graduated to $\frac{1}{10}$ cc. ($\frac{1}{5}$ cc. would amply fill all requirements); a stand or clamp to attach burette to side of wagon or box; one or more 50 cc. pipettes; a vial of

a concentrated alcoholic solution of phenolphthalein; a small vessel for measuring the soil. This may vary somewhat according to predilections of the user. Before going into the field the weight of a saturated soil, the corresponding weight of this same soil when dried at 110°, for soils of different textures, which this standard vessel will hold when exactly filled, is determined and the results are tabulated in the observer's note book. The texture of the soil, and in consequence the weights just referred to, can be determined by observation with remarkable accuracy after some practice in the field. Small glass vials, each containing 1.694 grams of pulverized acid potassium sulphate, carefully weighed and prepared in the laboratory, are carried or sent to the field parties as they may need them. This amount of the acid salt when dissolved in 250 cc. of water gives a N/10 solution, which is usually enough for a large number of determinations. The actual determination is made by taking from the cell of the electrical instrument used for determining the total salt content of the soil enough of the saturated soil to just fill the standard vessel. This is then carefully washed into one of the 250 cc. bottles, in which process a small copper funnel is found very useful. The bottle is then filled to mark, shaken vigorously for a few minutes, and allowed to settle for five minutes. Fifty cubic centimeters of the supernatant liquid is drawn off by a pipette and run into a tumbler, Erlenmeyer flask, or any convenient vessel. A few drops of the plenolphthalein solution are added, and if it indicates the presence of an alkali the solution is quickly titrated with the acid potassium sulphate solution. Supposing the apparatus and solution to have been assembled before starting on the day's work, this whole operation can be readily performed in from ten to twenty minutes, including the noting of the data. As five minutes of this time is available for other purposes, the method is undoubtedly a rapid one, and has proved from actual experience to be far more accurate than our requirements.

In developing this method some observations were made which seem worthy of noting. Calcium carbonate is somewhat soluble in water and is hydrolized so that the solution becomes slightly alkaline. The calcium carbonate is converted into a neutral salt by the acid potassium sulphate, so that a false reading may be obtained in estimating the sodium carbonate. In the case of soils or soil crusts this is of no importance, for it takes the calcium carbonate quite a little while to go into solution to a sufficient extent to make this effect noticeable, unless there be another salt such as sodium chlorid or sulphate present, when, as has been pointed out, one is entirely justified in regarding the alkalinity as due to sodium carbonate formed. In testing river or canal waters, however, which show a faint alkalinity, it is well to investigate whether the alkalinity may not be due to calcium carbonate alone. The question can usually be settled at once by testing for the presence of a chlorid or sulphate in the water, in which case when either of these is found the alkalinity may be safely regarded as due to sodium carbonate.

This method can not be considered as available for the reverse procedure—that is, to run the sodium carbonate from the burette into a solution of the acid potassium sulphate. This would be an advantage for some observers, if it were allowable, because one could then titrate to the appearance of color instead of to the disappearance of it. But acid potassium sulphate must be regarded as a strong acid, quite capable of decomposing carbonates, and by having it in excess, as has just been supposed, the acid sodium carbonate which would be first formed would then be more or less decomposed by the excess of acid, depending upon the temperature and concentration conditions, with the result that the readings obtained would inevitably be nonconcordant and a quantitative interpretation of them would be impossible.

INVERSION OF SODIUM BICARBONATE AND SODIUM BISILICATE.

The fact that acid sodium carbonate, or the bicarbonate, as it is often called, is an instable compound has been alluded to quite frequently in this paper. So, when solutions which contained the carbonate have been titrated to absence of color—that is, contain only the acid carbonate—are allowed to stand they gradually regain color, indicating the inversion of the bicarbonate and reformation of the carbonate. This has suggested a way of studying this inversion quantitatively, a knowledge of which would probably have great practical value as well as theoretical interest. This subject is now under investigation, but only preliminary results have been obtained as yet. It would appear that at the ordinary room temperature (18° C., about) the inversion proceeds quite rapidly, the curve being quite steep until equilibrium is nearly reached, when it suddenly becomes very flat and assumes an assymptotic character.

This reaction has now been very thoroughly tested for both sodium and potassium carbonates, and in the presence of their respective bicarbonates has proved itself most satisfactory. Among the applications of it which have suggested themselves is its use as a method for estimating the relative amounts of the carbonate and bicarbonate in the manufacture of soda and potash, for which up to the present time no satisfactory method has been found. It remains only to say a word as to the indicators. Other indicators have been successfully used, but phenolphthalein has proved by far the most satisfactory for the "sharpness" of the end reaction, the intensity of the color, and because one is not bothered by any change of color with mixed results, the color being entirely absent the instant the sodium carbonate ceases to exist as such.

It has been suggested that carbonates and bicarbonates can be estimated in the same solution by using phenolphthalein as the indicator for the normal carbonates and as soon as color disappears, methyl orange, which is a stronger acid than carbonic acid, being added and the titration continued. Serious objections have been made to this

method when the ordinary acids are used.[1] On the other hand it has apparently worked satisfactorily for the phosphates.[2] Mr. Briggs has found that when potassium hydrogen sulphate is the acid employed, the method is quite satisfactory for the alkaline carbonates and silicates. It is only necessary to add a few drops of phenolphthalein titrate to loss of color, add a little of the methyl orange at once and continue the titration; the difference between the two titrations giving the equivalent of sodium bicarbonate originally in the solution. A more critical examination of the method is now in progress.

It will be of interest to note in this connection some striking resemblances in the conduct of sodium silicate to that of sodium carbonate. As the salt of a weak acid it is hydrolized in water solution and shows a strong alkaline reaction with phenolphthalein. Carefully titrated with acid potassium sulphate until color just disappears, if allowed to stand it quickly shows a return of the color, which gradually becomes more intense. The explanation for this phenomenon is undoubtedly the same as for sodium carbonate. Further work along this line is in progress in this laboratory, and will be prosecuted as rapidly as circumstances will admit.

GENESIS OF HARDPAN.

The application of the present views regarding solutions to the study of hardpan phenomena gives promise of valuable as well as interesting results. A hardpan may be defined as a layer of the soil, usually near the surface, having the texture of the soil just above and below it, but more or less closely cemented by some material. In general, hardpan is a characteristic of soils where drainage is very poor or where standing soil waters may accumulate. The cementing material is often lime carbonate, but may be other material, as the hydrates of iron and alumina or silica. Hardpans vary very much in their physical properties. They are sometimes dense and close-grained as a well-characterized rock, requiring blasting or similar methods to break them up. In other cases they may be partly porous, and when brought to the surface disintegrated with ease, and there are all grades between these extremes.

The objections to their presence in the soil are evident. They prevent the penetration of plant roots, and, more important, they prevent the moisture from rain, irrigation, etc., sinking into the soil and thus being conserved for future use. They also prevent the water that may be beneath them from being drawn to the surface and made available for the plants.

The formation of a calcium carbonate hardpan is the most readily understood, and this has been dwelt upon at some length in a paper by Gardner and Stewart. It is there pointed out that resolution and re-

[1] Kuster. Zeit. anorg. Chem. 13, 127 (1896).
[2] Cavalier. Comptes rendus, 126, 1142, 1214, 1285. 127, 60 (1898).

precipitation are important factors. But when the calcium carbonate does not exist, as such, in the soil or in the vicinity, so as to be brought by water, while a limestone hardpan might form, under favorable conditions, it seems more probable that the cementing material would be one of the other substances mentioned, or a mixture of them.

The mineral constituents of the soil are for the most part salts, but with a few exceptions salts with a very limited solubility. Nevertheless, to some extent at least they are soluble, as are other salts, and their solubility may be increased or diminished by the presence of another salt solute, as has been indicated in a former part of this paper. These salts, carbonates, silicates, aluminates, ferrates, etc., are without exception salts of weak acids and may be expected to be much hydrolized in as far as they are soluble at all. This has been very beautifully illustrated in recent experiments by Clarke,[1] who has treated a large number of minerals carefully pulverized with pure water. On the addition of a few drops of dilute alcoholic phenolphthalein a marked alkaline reaction could be observed in the great majority of the cases investigated. The reaction may be indicated thus, assuming a very simple example to exist:

$$RSiO_3 + HOH \rightleftarrows ROH + H_2SiO_3$$
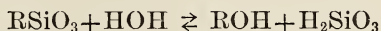
All these other substances are very slightly ionized in comparison with ROH. If R be a well-marked base, such as sodium or calcium, the solution will therefore be alkaline, as has been shown to be the case with calcium carbonates, sodium silicates, etc. The fact that the silicate is complex will not alter this general property. Precisely similar conduct is to be expected of aluminates and ferrates. This means that there will actually exist in the solution some of the hydrates of alumina, silica, or iron, as the case may be, which will remain as such on evaporation, though the absolute amount may be very small. The bases will be more or less readily removed, as they will be brought in contact with the carbonic acid and other acids (organic?) of the soil to form comparatively readily soluble salts.

This process probably plays an important part in the formation of bog-iron ore, which may be regarded as strictly analogous to a hardpan. The deposition of bauxite, for example, or the formation of a siliceous conglomerate is essentially of the same nature. But it should be remembered that in these latter cases when the action has been deep-seated with hot water as the solvent, the reagent has been much more ionized and so is much more efficient as a solvent.

An interesting case from southern California has recently come to our attention. The soil was shown to have been somewhat compacted under the plow sole. When the irrigating water was applied, this packed region of the soil caused a more or less temporary accumulation of the

[1] Jour. Am. Chem. Soc. **20**; 739 (1898).

waters. This soil, as can be readily seen under the microscope, con-tains a large proportion of unaltered mineral fragments, rich in iron and alumina and therefore well adapted to yielding these materials under the influence of the solvent action of the water; and, as a matter of fact, this packed material is found to rapidly become cemented with iron and alumina, as an examination in this laboratory showed. It is to be regretted that at the time this examination was in progress it was not deemed expedient to determine what constituents the irrigating water held which might augment its solvent power.

That other agencies are at work in the production of these phenom-ena may well be the case. For instance, oxidations undoubtedly have a significant rôle in this connection in breaking up the original miner-als. But it seems equally certain that the part that solutions play has not been given the consideration that it merits, mainly because solution phenomena have not been understood until comparatively recent years.

The study of hardpan formation necessitates a consideration of cer-tain physical phenomena; for instance, the movement of water and various solutions in the soil. This subject is receiving attention in this laboratory; but while a good many observations have been made and much valuable data collected, it is yet too soon to formulate a complete hypothesis for this subject. The views here described are put forward in the hope of furnishing an incentive to more widespread interest and work on this important subject.

THE RÔLE OF FERTILIZERS.

In the action of fertilizers on the soils there is very much to be learned; for, in spite of the great amount of attention that has been given to this important subject, it can not fairly be claimed that we have made much more than a beginning. While it has long been acknowledged that the disintegration of the mineral constituents of the soil, through the agency of the fertilizer, is a factor in its use, and that solution phenomena are important in this connection, but very little advance has been made in this direction, and its full importance has not been appreciated. It can not fail to be of advantage to inves-tigators in this field to give this point of view more consideration in the future; for it is indisputable that the mineral constituents of the soil are salts soluble to at least some extent, and affected in their solu-bility, as are other salts, by the presence and nature of other solutes in the soil solutions. It becomes of the first importance, therefore, in determining the use of any particular fertilizer to consider its probable conduct on contact with water—what ions it will yield, if it be an electrolyte, and how these ions will affect the solubility of the soil ingredients, and thus bring into activity products which may be of value as plant nutrients. No less desirable is information of this char-acter than is that of the physical effect as modifying the texture or moisture content, for example. or in forming new compounds more or

less desirable; and in the study of this latter point the ideas here suggested will be found to have much use. That they will lead to further work on the purely physical side of the problem is not the least of the advantages in their consideration; for it does not seem too much to hope that the near future will bring us most helpful and practical information as to selective absorption of solutes by soils and as to the change of vapor pressure in soil solutions, important as modifying the moisture content of the air in contact with the soil. Other questions of a kindred nature will suggest themselves, and the time is ripe for a larger, broader and more scientific attack on these important problems of agriculture.

SUMMARY.

In this paper there have been presented:

1. An outline of the theory of solutions, showing that a solute by virtue of the presence of the solvent behaves as though it were a gas, and that electrolytes present the added phenomena of electrolytic dissociation or ionization.

2. A demonstration that the reactions under investigation are of a reversible type, and in consequence the Mass law is applicable to a study of the equilibria among the solutes.

3. An application of these views, showing how the solubilities of the sulphate and carbonate of lime in nature are increased by the presence of a solute which dissociates but yields no common ion.

4. An announcement of the presence of sodium carbonate in the waters of the Great Salt Lake, Utah, and an explanation of why this fact has previously escaped observation, based on the relation which obtains between the ionization products and the solution constant. A similar explanation is offered for the scant amount of lime in the waters of this lake.

5. An examination of the hypothesis of Hilgard as to the rôle of carbon dioxid in the genesis of alkali, in which it is demonstrated that the phenomena observed are more satisfactorily accounted for in terms of the theory of solution, and that the carbon dioxid must be regarded as a contributing cause, but not a necessary one.

6. An examination of the Hilgard method for the reclamation of black alkali soils, with an explanation of the reactions observed and of the importance of the controlling conditions respecting drainage and the accumulation of carbon dioxid, empirically announced by Hilgard.

7. An examination of the reaction between calcium sulphate and the carbonates of ammonium. The use of gypsum for conserving ammonia in manure piles is explained. Some errors, with the reasons therefor, which may accompany the use of ammonium carbonate in analytical operations involving salts of the alkaline earths are pointed out.

8. A discussion of some analytical problems in a chemical examination of alkali soils. The nature of the problems is made clear. The

relative merits of leaching the soils and taking a solution in contact with the soil in preparing the sample are discussed, and the advantages in favor of the latter procedure indicated. The necessity of making a direct estimation of each constituent is demonstrated.

9. A plea for the rational statement of analytical data, inasmuch as it is the ions which are determined and not the salts. Furthermore, it is the ions with which we are generally concerned in the study of any particular problem.

10. A field method for the estimation of sulphates, chlorids, and carbonates, involving three titrations which may all be made on the same sample in one vessel. Its use in reconnoissance work is described.

11. A rapid method for the estimation of sodium carbonate in the presence of the bicarbonate, depending on the conversion of the alkaline carbonate to the neutral acid carbonate, with the formation of a neutral sulphate by the addition of acid potassium sulphate. The use of the method in the laboratory and in the field is described, and its probable availability for technical work is suggested. The objections to the use of sulphuric acid in determining "alkalinity" are made evident.

12. Observations on the hydrolysis of sodium carbonate and sodium silicate and the inversion of sodium bicarbonate and sodium bisilicate to the normal salts are described briefly.

13. A discussion on the formation of hardpan and similar deposits, in which it is pointed out that the hydrolysis of the salts of weak mineral acids and subsequent desiccation and deposition of the solution products must be taken into account in any hypothesis as to their genesis.

14. An explanation of the solution and hydrolysis of certain minerals and the consequent alkalinity they display.

15. Suggestions for the study of the functions of fertilizers, in which the importance of considering the solution phenomena which their presence may effect in the ground waters is made evident.

16. Some observations on selective absorption and other physico-chemical phenomena which are incidental to a complete study of the properties of a soil.

SOME NECESSARY MODIFICATIONS IN METHODS OF MECHANICAL ANALYSIS AS APPLIED TO ALKALI SOILS.

By LYMAN J. BRIGGS.

INTRODUCTION.

Many alkali soils present peculiarities in composition which do not permit the use of the ordinary methods of determining their mechanical composition. It consequently seems desirable to call attention to certain modifications in the methods of examination which have been found useful in determining the mechanical composition of samples of alkali soils collected by the field parties of this division.

The following points will be considered:

(1) The disintegration of the soil during the progress of the analysis, resulting from the solvent action of the water used in making the mechanical separation.

(2) Apparatus and method for examining soils subject to excessive disintegration during mechanical analysis, and the advantages of the centrifugal method as applied to all soils.

(3) The treatment of the mechanical separations after ignition to convert the oxides of the alkaline earths into carbonates.

(4) The determination of the water-soluble salt content of soils in connection with their mechanical analyses.

MECHANICAL ANALYSIS OF SOILS SUBJECT TO EXCESSIVE DISINTEGRATION.

Many of the soils of regions requiring irrigation contain considerable amounts of gypsum ($CaSO_4+2H_2O$) and calcium carbonate. In many cases these substances will be found cementing together a number of soil particles, forming an aggregate grain of considerable size. These soils in consequence generally have a somewhat open structure, similar to that of a fine sand, through which water moves rapidly.

When these soils are placed in a considerable quantity of water, as in the beaker method of elutriation, this cementing material dissolves sufficiently to break up the aggregate and release the smaller particles, thus materially changing the nature of the soil. This is most marked

in the case of the gypsum soils on account of the greater solubility of this cement. The solubility of such a cement is considerably increased by the presence of other salts in solution which have no ion in common with those of the cementing material. The dissociated salts react with the calcium sulphate or calcium carbonate in solution to form, to a greater or less extent, all the chemical compounds possible through a rearrangement of the ions of the original substances. As a consequence, more of the cementing material goes into solution and the reactions continue until a condition of equilibrium has been reached. The equilibrium is, of course, disturbed by the addition of water or by changes in temperature. A more detailed statement of these mass reactions will be found in an accompanying paper by Dr. F. K. Cameron.

From these considerations it becomes evident that neither the Osborne beaker method nor the elutriator method of Hilgard, both of which require large amounts of water, is applicable to the mechanical analysis of such soils. A trial of the beaker method on a gypsum soil from New Mexico confirmed these conclusions, fresh amounts of "clay" being liberated after each successive addition of distilled water. The determinations by this method differed widely, the amount of finer material increasing with the time employed in the separations. In fact, the amount of "clay" obtained when the soil was allowed to stand in contact with water for some time was sufficient to indicate a soil of close structure, permitting water to pass very slowly, instead of the open, porous structure which the soil was known to possess.

It becomes evident that in order to get an analysis which would fairly represent field conditions it is necessary to make the analysis as rapidly as possible and with the use of a minimum amount of water. For this purpose the centrifugal method has been used with satisfactory results. The small amount of water required and the rapidity with which the separations can be effected tend to reduce materially the amount of gypsum going into solution. The composition of the gypsum soil, as determined by this method, shows a much smaller quantity of clay and a proportionally larger amount of larger particles. This undoubtedly represents much more nearly the mechanical composition of the soil *in situ*. The mechanical composition of such soils must be, at best, somewhat indeterminate, owing to the fact that so large a percentage of the soil consists of water-soluble material.

THE CENTRIFUGAL METHOD.

The use of centrifugal force to hasten the deposition of particles in suspension naturally suggests itself as a means of shortening the tedious process of making separations by the method of sedimentation. Hopkins[1] appears to have been the first to describe this method in detail,

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[1] Proceedings of the Fifteenth Annual Convention of the Association of Official Agricultural Chemists, Bulletin 56, Division of Chemistry, U. S. Department of Agriculture, 1898, page 67.
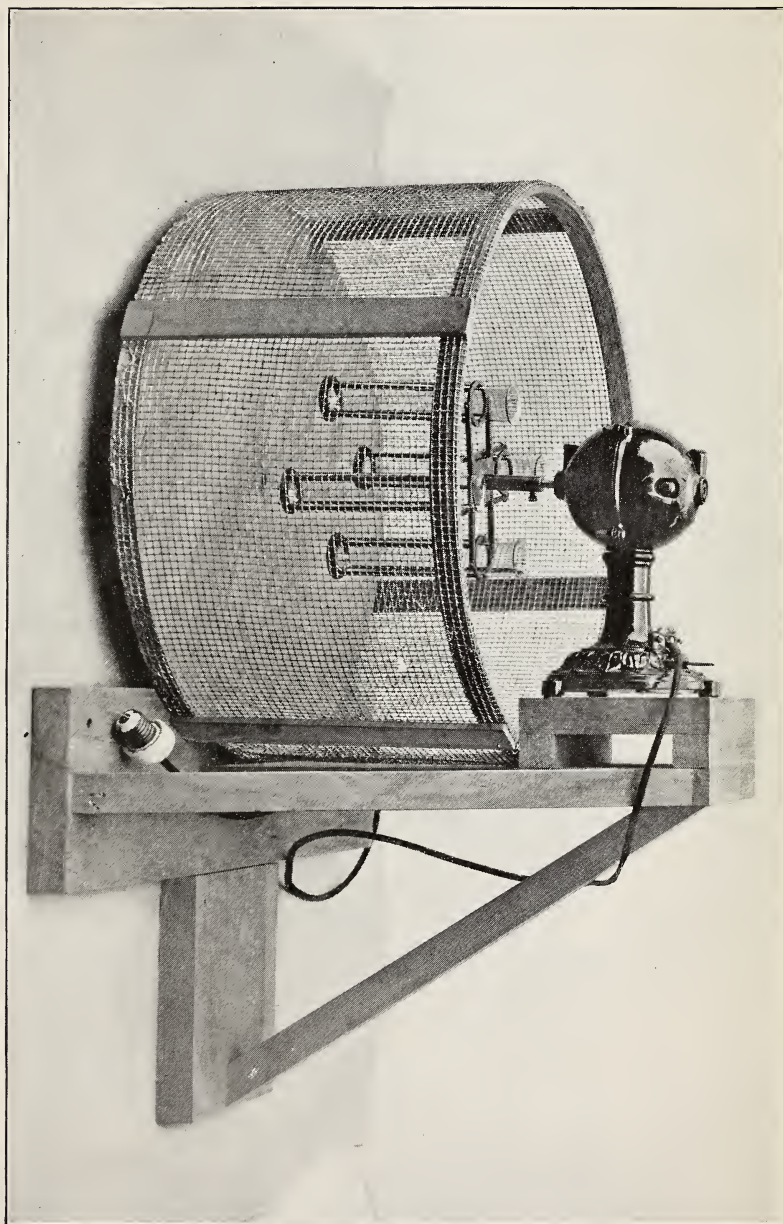
although the device had been previously used by several soil investigators. The method has been found so satisfactory in this laboratory on account of its quickness and convenience and its applicability to all soils that it is believed that a description of the apparatus and the method of operation will prove of interest.

The apparatus necessary for making analyses by the centrifugal method is inexpensive and simple in construction. The primary requisite is some means of securing the necessarily high velocity required for throwing down the soil particles from suspension. An electric motor is most suitable for this purpose if an electric-lighting current is available. A water motor can be used, although subject to annoying interruptions and fluctuations in speed unless an independent water supply can be obtained. Some form of centrifugal apparatus operated by hand can be employed where but few samples are to be analyzed, although this method will be found to lack the advantage arising from an apparatus operated at a constant speed, such as may be obtained by the use of an electric motor.

The centrifugal apparatus as designed by the writer for making mechanical analyses in the Division of Soils is illustrated in Pl. XXVIII. The power is obtained from a Holtzer-Cabot, 110-volt, 16-inch fan motor. This motor uses a current a little in excess of that required for an ordinary 16-candlepower lamp, and will carry 4 centrifugal tubes of the dimensions described without serious heating. This style of motor is supplied with a rheostat in its base, enabling four different speeds to be obtained, which is a great advantage in making separations, besides enabling the motor to be gradually brought up to speed. The rheostat is also provided with an open contact point for stopping the motor.

The fan and fan guard being removed, the motor is firmly screwed to a rigid supporting frame with its armature shaft vertical. A second hollow shaft, milled to fit the armature shaft, is slipped over the latter and fastened by a set screw. To the lower end of the hollow shaft are fastened four horizontal arms, each being about 8 cm. long and consisting of two parallel bars of 5 mm. square brass, $4\frac{1}{2}$ cm. apart   A brass ring 5 mm. thick is trunnioned between each pair of bars at their free ends, and four light brass rods extend downward from this ring to a similar ring 15 cm. below. This trunnioned system swings outward and upward in the well-known way when the motor gathers speed. It is important that the system should swing freely, and care should be taken that the trunnion screws are sufficiently massive to stand the strain to which they are subjected at high velocities.

Large heavy test tubes (18 by 3 cm.) serve admirably for the centrifugal tubes. The aperture in the upper metal ring is made large enough to admit the test tube easily, while the opening in the lower ring is somewhat smaller and provided with leather or cork washers, on which the test tube rests. A guard consisting of a screen of 5 mm. mesh

surrounds the movable portion of the apparatus as a safeguard against accidents. To protect the motor, the wires leading from the lighting current should contain fuses which will melt for currents exceeding two or three amperes.

The analyses of four samples may readily be carried on at the same time. Ten grams constitute a suitable sample for analysis in an apparatus of the dimensions described. The preliminary preparation consists in agitating the sample of soil with about 200 cm. of water in a mechanical shaker[1] from six to eight hours, or until the surface of the larger grains, as seen under the microscope, appear to be clean and free from clay particles.

A portion of the contents of each shaker bottle is transferred to its corresponding centrifugal tube. The apparatus is then rotated for a length of time sufficient to throw down from suspension all particles larger than those which it is desired to retain in the finest separation. The "clay" water is then decanted into beakers and the remainder of the contents of the shaker bottles transferred to the tubes, the heavier material being thrown down as before. An important feature of the operation now claims consideration. In making additions of distilled water to the tube to effect further separations of "clay," it is desirable and important that this water should be forced in under considerable pressure. This forms the most satisfactory and convenient means of getting the material at the bottom of the tube into suspension again, being far superior to any agitation with a stirring rod or a rubber pestle, since it avoids all abrasion and the necessity of washing off the stirring rod each time. It will be found that thorough stirring of the material in the bottom of the tube by the jet of distilled water each time a decantation is made will materially shorten the time and diminish the amount of water required for an analysis. The apparatus for securing this pressure will be referred to later.

When the "clay" has all been separated, as determined by a microscopic examination, using a micrometer, the tubes should be rotated for a shorter time, or at a lower rate of speed, leaving the particles constituting the next separation in suspension. The water containing these particles is then decanted into separate beakers and the process repeated until the separation of the second grade is effected.

In making separations of particles exceeding 0.01 mm. in diameter, the sedimentation is sufficiently rapid to avoid the necessity of using centrifugal force. The distilled water is, therefore, added by means of the jet, and the material in suspension allowed to subside for a suitable length of time, as in the beaker method. Two separations, the clay (0.005 to 0.0001 mm.) and fine silt (0.01 to 0.005 mm.), are thus made by the use of centrifugal force. The silt (0.05 to 0.01 mm.), is separated by simple subsidence. The material remaining in the tube constitutes

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[1] Whitney, Bulletin 4, Division of Soils, U. S. Department of Agriculture, 1895, page 9.

the sands, which are dried and separated by means of sieves and bolting cloth.

The clay water does not usually exceed 600 cc., while the fine silt and silt together require about 500 cc. If these two last-named separations are allowed to stand for a day or more, they will, of course, settle to the bottom of the beakers, but the water in which they were suspended will be found somewhat turbid, indicating the presence of clay. No matter how carefully the separations may be made, this turbidity will nearly always occur, indicating a slight disintegration of these separations into finer material. This turbid water may be added to the water containing the "clay" in suspension if desired, although one will be justified in combining this suspended material with the sediment from which it was obtained. This latter method is preferable in soils containing large amounts of soluble material, such as the gypsum soils.

If desired, the silt and fine silt sediments can be confined to very small volumes of water by again passing them through the centrifugal apparatus at a high velocity, which throws down all sediments, leaving the clear water which may be decanted. This sediment may then be washed with a small quantity of water into small platinum evaporating dishes. As recommended by Hopkins, it is highly desirable to evaporate the whole of the clay water, the volume being so small as to permit this being readily done. Porcelain dishes are suitable for evaporating the liquid to a small volume, when it may be transferred to platinum dishes for ignition.

Fig. 11.—Apparatus for water pressure in mechanical analysis.

In figure 11 is shown the device employed for obtaining a jet of distilled water under pressure. The air-tight reservoir R is filled by opening the valve A in the pipe leading from the distilled water tank, and by opening the vacuum cock V. After filling, V and A are closed and air admitted from the pressure cock P, thus submitting the water to a pressure of about 8 pounds per square inch. This gives a jet sufficiently strong to thoroughly stir up the sediment in the bottom of the centrifugal tubes, which through centrifugal action is packed so tightly in the tube as to permit an almost complete decantation of the water.

The following mechanical analyses in duplicate serve to illustrate the accuracy which one may reasonably expect to attain in regular laboratory determinations, using the centrifugal method. These analyses were made by Mr. R. T. A. Burke, of this laboratory.
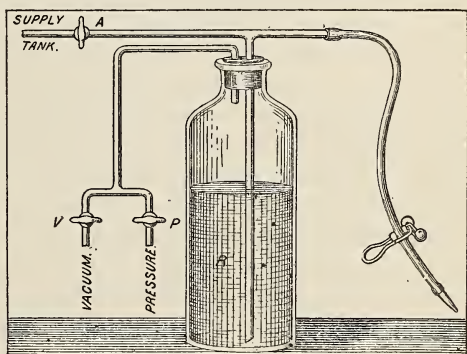
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Mechanical analyses in duplicate by the centrifugal method.

Diameter.	Conventional name.	4333.		4335.	
		a.	*b.*	*a.*	*b.*
Millimeters.					
2. to 1.	Fine gravel...........	....	....	1.80	1.26
1. to 0.5	Coarse sand	0.11	0.09	.84	.88
0.5 to .25	Medium sand..........	.66	.62	1.26	1.16
.25 to .1	Fine sand	7.78	7.67	2.02	2.40
.1 to .05	Very fine sand........	42.67	41.95	13.35	13.38
.05 to .01	Silt	27.04	28.65	34.52	35.49
.01 to .005	Fine silt..............	.85	.94	4.64	4.52
.005 to .0001	Clay	11.91	11.80	29.28	28.37
Loss at 110° C		1.03	1.01	2.14	2.18
Loss on ignition.....................		6.87	6.80	8.30	8.16
Soluble salts		.95	1.01	1.68	1.69
Total.............................		99.87	100.54	99.83	99.49

TREATMENT OF SEPARATIONS AFTER IGNITION.

In making mechanical analyses it is customary to determine the organic matter and combined water by igniting to redness a separate five-gram sample, which has previously been carefully dried at 100° to 110° C. It is consequently necessary to ignite also the several separations of the mechanical analysis before weighing the sample. If calcium or magnesium carbonates are present they are partially reduced through ignition to the oxides of these metals. These oxides must therefore be converted back into carbonates before making the final weighing.

The method commonly employed for this purpose, and the one recommended by the Association of Official Agricultural Chemists,[1] consists in treating the ignited separations with a saturated solution of ammonium carbonate after being cooled. The reaction may be expressed thus:

$$CaO + (NH_4)_2CO_3 \leftrightarrows CaCO_3 + 2NH_3 + H_2O$$
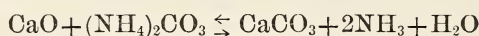
The separations are then dried and afterwards heated to dull redness in order to drive off the ammonia, water, and excess of ammonium carbonates. They are then cooled in a desiccator and weighed. Such treatment is not necessary for normal sodium or potassium carbonates, as these salts are stable and non-volatile at a red heat.

This method answers very well if the separations contain only carbonates. If, however, chlorids, sulphates, or nitrates are present two sources of error occur.

In the first place, these salts are more or less volatile at the red heat required to burn off *all* the organic matter, so that an actual loss from volatilization will occur to some extent. Unfortunately, this difficulty is inherent in the method of determining organic matter by loss on combustion, which is the most satisfactory method available in connection with mechanical analyses.

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[1] Methods of Analysis, 1898. Bul. No. 46, Div. of Chemistry, U. S. Dept. of Agr.

Secondly, if chlorids, nitrates, or sulphates are present in the ignited separations, the addition of ammonium carbonate to convert the oxides results in the formation of the ammonium salts of these acids. The reaction between the two salts is similar to that mentioned when speaking of gypsum in the presence of some other salt, and a condition of equilibrium is reached in exactly the same way. The class of reactions may be represented as follows:

(1) $CaSO_4 + (NH_4)_2CO_3 \leftrightarrows CaCO_3 + (NH_4)_2SO_4$
(2) $2NaCl + (NH_4)_2CO_3 \leftrightarrows Na_2CO_3 + 2NH_4Cl$
(3) $2NaNO_3 + (NH_4)_2CO_3 \leftrightarrows Na_2CO_3 + 2NH_4NO_3.$

The ammonium salts of the above-mentioned acids are all volatile and will, of course, be driven off when the separation is heated to remove the excess of ammonium carbonate. The error from this source was called attention to some time ago by Hilgard and Jaffa.[1] If chlorids, nitrates, or sulphates are present in considerable quantities, the above reactions will be indicated by the presence of the characteristic dense white fumes of the corresponding ammonium salts, which are freely given off at comparatively low temperatures. Ammonium carbonate shows no fumes on vaporization.

By successive treatments with ammonium carbonate it is possible to remove all of the negative or acid ions in this way, the positive or basic ions with which they were originally combined remaining as carbonates. The fact that a salt non-volatile at low temperatures is formed at the same time as the volatile ammonium salt reduces considerably the loss due to the above reaction, owing to the similarity in the reacting weights of the initial and residual salts as, for example, NaCl and $\frac{1}{2}$ Na_2CO_3. The change in reacting weights for the three cases considered is given below:

Salt.	Reacting weight.
$CaSO_4$	68
$CaCO_3$	50
NaCl	58.5
Na_2CO_3	53
$NaNO_3$	85
Na_2CO_3	53

This may, in part, account for the failure of soil analysts in general to consider this important source of error, particularly in connection with alkali soils.

As pointed out by Hilgard and Jaffa,[2] this loss may be avoided and the oxides converted into carbonates by treating directly with carbonic acid gas. A small amount of water is added to the ignited soil through which carbonic acid from a Kipp's apparatus is allowed to pass slowly for one or two hours. The separations are then evaporated to dryness and ignited at a *dull* red heat. The separate sample employed in determining the organic matter must also be subjected to the same treatment.

[1] Proceedings of the Society for the Promotion of Agricultural Science, 1888, p. 40.
[2] *Loq cit.*

DETERMINATION OF WATER-SOLUBLE MATERIAL.

A determination of the amount of water-soluble salts in a soil has heretofore seldom been made in connection with a mechanical analysis. This determination is of so much importance and interest, especially in connection with soils requiring irrigation, that it is now performed in this laboratory for all soils.

Two methods are available for this determination: First, the evaporation to dryness of an aliquot part of the clear solution and weighing the solute; second, the determination of the concentration of the solution through its electrical conductivity, computing from this data and the volume of the solution the amount of salt.

The greatest difficulty in using the gravimetric method is to obtain the solution clear and free from suspended or colloidal clay. This is best effected by the use of repeated filtration through hardened filters. This process is, however, very laborious, and with some soils it is almost impossible to separate the clay, while with other soils the clay readily flocculates, either subsiding and leaving a clear supernatant liquid, or forming aggregates which can readily be removed by the filter. In most cases this flocculation appears to be due to a rather large amount of salts in solution. Evaporation to dryness will sometimes prevent clay from becoming suspended when water is again added. Ignition will nearly always accomplish this, but at the expense of a portion of the salt content, as will be shown later.

The electrical method of determining the soluble salt content has the important advantage of not requiring any filtration of the solution, the presence of the suspended clay having no appreciable influence upon the conductivity. The determination is consequently very rapid, consisting simply in measuring the specific resistance of the solution and noting its temperature and volume. The resistance of the solution is conveniently determined with the apparatus previously described by the writer.[1]

The transformation of the observed electrical resistance of the solution into terms of solution concentration may be performed by one of the three following methods:

(1) The approximate composition of the salts in an area throughout which the composition (not the amount or concentration) may be fairly assumed to be uniform is determined by chemical analysis. An aqueous solution of these salts of known concentration is then prepared, the salts being present in the solution in the proportions previously found by the analysis. From this standard solution other solutions of regularly diminishing concentration are prepared and the electrical resistance of each determined in the electrolytic cell to be used in subsequent measurements. From these data a resistance-concentration curve

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[1] Electrical Instruments for Determining the Moisture, Temperature, and Soluble Salt Content of Soils, Bulletin No. 15, Division of Soils, U. S. Department of Agriculture, 1899.

can be constructed, from which the concentration of any unknown soil from that area can at once be determined if its electrical resistance is known.   The original solution must exceed in concentration any of the solutions of unknown concentration, while all solutions must be reduced to a common temperature.   This reduction is very simple, a table for this purpose being given in Bulletin No. 7 of this division.

The weight of the soil used and the volume of the solution being known, the amount of the soluble salts in any sample can be expressed as a percentage of the dry weight of the soil.   As far as accuracy is concerned, this method is practically as reliable as a direct determination by the gravimetric method.   On account of the time required for the necessary chemical analysis this method is not well adapted to a determination of the salt content of a small number of samples unless a chemical analysis of the water-soluble material has been made for other purposes.

(2) The second method of determining the soluble salt content consists in making a concentrated solution from a soil crust or a soil highly charged with salts.   A portion of this solution is evaporated to dryness, in order to determine the concentration, while from the remaining portion a series of solutions of decreasing concentration is formed, the resistance of each solution being determined as before and the resistance-concentration curve prepared.   This method requires much less preliminary work than the first, and is just as accurate, having a gravimetric basis.   A quantitative knowledge of the composition of the soluble material in this case is not obtained.

(3) If the sample is an isolated one, or if the number of samples from any locality is so small that it is not desired to prepare a resistance-concentration curve, a very fair approximation to the salt content can be obtained by using a resistance-concentration curve for some single salt, such as sodium chlorid.   For dilute solutions, all of the more strongly dissociating salts, such as chlorids, nitrates, and sulphates, are practically ionized to the same extent.   Aside from the slight differences in the migration velocities of the ions, which in this case may be neglected, these strongly dissociating salts in dilute solution have practically identical concentration-resistance curves, if we use ionic concentration in place of the conventional mass of the solute, or, in other words, if we express the concentration in gram-molecules instead of in percentage of solute by weight in the solution.   Therefore, it is practicable to use this common concentration-resistance curve (the concentration being expressed in gram-molecules) to determine the salt content of dilute soil solutions.   To convert this determination into grams of solute per liter, it is simply necessary to multiply it by the reacting weight of the salt in the terms of which it is desired to express the concentration.   The per cent of salt as determined by this method will consequently vary somewhat, depending upon the reacting weight of the salt chosen as a basis of computation.   For example, if the

solute was computed as sodium chlorid the factor used would be 57, while for sodium sulphate (a bivalent salt) the factor would be 142/2, or 71.

Using a concentration-resistance curve computed on a gram-molecular basis, we can thus compute the salt content in terms of any salt desired. If it is preferred to express all results in terms of some single salt or a combination of salts, a resistance-concentration curve can be prepared directly as in the first two methods, the concentration being expressed in terms of the mass of solute.

In the salt determinations made in this laboratory in connection with the mechanical analyses no effort has been made to maintain a constant relation between the amount of soil and the volume of the solvent. The volume of the water necessary in separating the clay (about 600 cc.) is so large in comparison with the amount of salt in a 10-gram sample of soil that a considerable variation in the volume of the solvent would have but little influence upon the amount of salts in solution, except in the case of slightly soluble salts. Since these salts under soil conditions exert but little influence upon the plant, so far as their concentration is concerned, the procedure outlined appears justifiable.

The "clay" water is generally found to contain the principal portion of the soluble matter, which is determined and subtracted from the weight of the combined clay and salt separation to give the amount of clay. The presence of any appreciable amount of salt in the "fine silt" or "silt" waters is easily determined by the instrument; and it can be neglected, combined with the clay water, or determined and subtracted from the "fine silt" or "silt" determinations as the case demands.

The following table gives the salt content of three alkali soils determined by three different methods. These soils were selected to show wide variations in their soluble salt content. The determinations were made by Mr. W. G. Smith of this laboratory.

Salt content.

Catalogue No.	1.	2.	3.
	Per cent.	Per cent.	Per cent.
4115	1.60	1.08	0.97
4119	5.40	4.65	4.55
4131	3	2.70	2.63
Average	3.33	2.81	2.71

The first column of the table gives the catalogue number of the soils investigated. Column 1 gives the per cent of salt found by the electrical method after two grams had been left to stand for six days in contact with 600 cc. of water. The salt is expressed as the percentage of the dry weight of the soil. Column 2 gives the per cent of salt found after evaporating the solutions used in No. 1 to dryness, igniting, diluting to 600 cc., and allowing them to stand for six days. Column 3 gives

the salt content determined gravimetrically by evaporating to dryness the clear solution used for the determination given in column 2. No difficulty is experienced in obtaining a clear solution from any ignited soil, the clay seldom showing any tendency to remain in suspension after ignition.

The results of the table show that the determination of the salt content after ignition is not advisable, a considerable portion of the soluble matter either being driven off during ignition or else converted into an insoluble form. The results of columns 2 and 3 show a satisfactory agreement between the electrical and gravimetric determinations, considering that the concentration-resistance curve used in converting the electrical determinations was one prepared for a series of soils, of which the three samples selected formed but a small proportion. The salt determinations in the two duplicate analyses given on page 178 serve to illustrate further the accuracy of the electrical method.

SALTS AS INFLUENCING THE RATE OF EVAPORATION OF WATER FROM SOILS.

By LYMAN J. BRIGGS.

INTRODUCTION.

The physical properties of water which influence the rate of evaporation from a soil surface are surface tension, viscosity, and vapor pressure. Since these factors are all modified to a greater or less degree by the addition of different quantities of salts, it is of interest to consider the influence of various salts in solution upon the evaporation of water from soils.

The surface tension of an aqueous solution of a salt is higher than that of the solvent. It appears from the work of Dorsey[1] upon dilute solutions and of Sentis[2] upon solutions greater than one-half normal that the surface tension is a linear function of the concentration. This may be represented by

$$T_s = T_w + Kc$$

in which T_s is the surface tension of a solution containing c gram equivalents per liter, T_w the surface tension of water at that temperature, and K a constant varying with different salts. For sodium chlorid this constant K may be taken as 1.5 dynes, and for sodium carbonate as 2 dynes per square centimeter. Since the surface tension of pure water is about 73 dynes per square centimeter at 18° C., a difference of one gram equivalent in the concentrations of two portions of the soil solution would cause an increase in the surface tension of 2 per cent for sodium chlorid and 2.6 per cent for sodium carbonate.

The writer[3] has previously pointed out that the capillary movement of water in soils is due to the pressure of the peculiar capillary surface formed by the water in the capillary space about the point of contact

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[1] Physical Review, 5, p. 228, 1897.

[2] Jour. de Phys. (3), 6, p. 183, 1897.

[3] The Mechanics of Soil Moisture, Bulletin No. 10, Division of Soils, U. S. Department of Agriculture, 1897.

of two soil grains. The pressure of such a surface may be represented by

$$P = T \left(\frac{1}{r_1} + \frac{1}{r_2} \right)$$

in which P is the pressure, T the surface tension, and r_1 and r_2 the two principal radii of curvature. Since T is involved only as a linear function, a small change in T can only produce a proportional change in P. Consequently the small changes in T, which amount to only 2 per cent in the extreme variations considered, can practically be neglected as compared with the much greater variations in the value of r. In other words, the salts in solution play a minor part as compared with the curvature of the water surfaces in determining the capillary movement of water in soils.

Since the viscosity of a solution increases with the concentration, the presence of large amounts of soluble salts would retard to some extent the movement of water in the soil, and so lessen the rate of evaporation by limiting the movement toward the surface. Arrhenius has found that the relation between viscosity and concentration for a large number of solutions can be expressed by the equation :

$$\mu_n = \mu_1{}^n$$

in which μ_n is the specific viscosity of a normal solution referred to the solvent at the same temperature and n the number of gram-molecules in the solution under consideration. For example, a normal solution of sodium chlorid has a specific viscosity of 1.097, or about 10 per cent greater than water. The specific viscosity of a two-normal solution would be 1.20 and a half-normal 1.04. Since a saturated solution of sodium chlorid at ordinary temperatures contains approximately five gram-molecules per liter, the specific viscosity under such conditions would be 1.59. In alkali soils, therefore, where the salts are present in excess, the increased viscosity of the solution would decrease the rate of movement of water to a considerable extent. It should be noted in this connection that the effect of increased concentration is to increase the surface tension, and thus increase the rate of movement. The two factors, consequently, oppose each other, and the resultant change in the rate of movement of water due to change in concentration is much less than if either factor existed alone.

Finally, the vapor pressure of a salt solution decreases with increase of concentration. The vapor pressure of a normal sodium sulphate solution at 100° C. is 25 millimeters less than the pressure of water vapor at that temperature. The variation in vapor pressure from that of the solvent at other temperatures has not been determined for this salt; but approximate values can be ascertained by comparison with the approximate normal solution of potassium hydrate, for which the vapor

tension at various temperatures has been determined.[1]   In the following table the first column gives the temperature, the second and third columns give the vapor pressure of the solution and of the water at the temperature considered, while the fourth column gives the temperature to which it would be necessary to cool pure water in order to make its vapor pressure equal to that of the potassium hydrate solution:

Tem- perature 0°C.	Vapor pressure.		Tempera- ture of water for equal vap. pr.
	16.6 per cent KOH.	Water.	
10	8.01	9.14	° 8.1
16	11.85	13.51	13.9
20	15.25	17.36	17.9
25	20.67	23.52	22.8
30	27.74	31.51	27.8
34	34.84	39.52	31.8

It will be seen from the table that the evaporation from a normal salt solution at 30° C. into vapor free space is the same as with pure water at 27.8°.   A certain conservation of the moisture would consequently follow.   However, even with a normal solution this is not very marked and could only have an important effect in case the soil moisture is saturated with the salt.   A saturated solution of sodium carbonate would correspond in rate of evaporation to a lowering of temperature of about 10° C., assuming the evaporation to be taking place in a vacuum.

There is another factor which probably exerts more influence upon the rate of the evaporation of water than any of the factors mentioned, namely, the physical condition of the surface of the soil.   Hilgard has pointed out that some of the so-called alkali salts, especially sodium carbonate, exert a marked influence upon the physical character of the soil.   Buffum[2] calls attention to this fact and also states that alkali soils may appear damp when adjoining lands seem dry.   To explain this phenomenon he conducted experiments on soils which had been moistened with solutions of salts.   The salts used were sodium carbonate, sodium chlorid, sodium sulphate, and magnesium sulphate in solutions varying in concentration from 0.1 per cent to 9 per cent.   The general results of the experiments show that the amount of water lost from the pots containing 9 per cent solutions (which is equivalent to 2.2 per cent alkali, in a soil containing 25 per cent of the solution) was approximately one-half as much as that from soils containing the same percentage of pure water.   The effect of the presence of soluble salts in the soil on the evaporation, in Buffum's experiments, was so much

[1] Landolt and Bornstein, "Phys. Chem. Tab.," S. 68.
[2] Bulletin No. 39, Wyoming Experiment Station, p. 55, 1898.

greater than would be expected from the theoretical considerations given in the first part of this paper that the writer was led to believe that this difference was due to a change in the surface conditions of the soil from the accumulation of salts rather than from the presence of the salts in solution. In other words, either the formation of a mulch or the crusting of the soil at the surface had taken place, preventing evaporation to some extent. To test the validity of this opinion the following experiments were planned:

(1) The evaporation of water from soils spread out in thin layers in large trays, one sample being moistened with distilled water and the other with a salt solution. The soils in both trays to be stirred from time to time in order to prevent any possible crusting of the soil. This would indicate whether the abnormal lessening of the evaporation observed by Buffum was due to a surface condition.

(2) The relative rate of evaporation in open dishes of pure water and solutions of the concentration used in experiment (1), as a check upon the conditions observed during that experiment.

(3) Evaporation from the surface of soils packed in tall, narrow cylinders and moistened with pure water and salt solutions, as a repetition of Buffum's experiments. This arrangement would serve to accentuate the effect of the crusting of the surface.

The soil used in all the experiments was from James Island, South Carolina, being the soil upon which the Sea Island cotton is grown. The texture is shown in the accompanying mechanical analysis, made by Mr. W. G. Smith, of this laboratory:

Diameter.	Conventional name.	86. James Island, S. C.
Millimeters.		*Per cent.*
2 to 0.1	Fine gravel.......... ..	0.00
1 to .5	Coarse sand	.37
.5 to .25	Medium sand..........	6.01
.25 to .1	Fine sand.............	79.15
.1 to .05	Very fine sand.........	2.50
.05 to .01	Silt....................	.55
.01 to .005	Fine silt..............	4.23
.005 to .0001	Clay...................	4.60
Loss at 110° C.....................		.83
Loss on ignition		1.85

SODIUM CHLORID.

Experiment 1.—To test the influence of the salt content of the soil upon the rate of evaporation of water from the soil, two samples of soil containing 200 grams each were moistened, respectively, with 40 grams of pure water and normal sodium chlorid solution. These soils were spread out in two shallow photographic trays of the same size, measuring approximately 8 by 10 inches. The soil containing the salt solution was frequently stirred, in order to prevent the possible formation of a crust at the surface. The soil in the other tray was also stirred at

the same time, in order to treat the two soils as nearly alike as possible. The results of the experiment are given in the following table, and shown graphically by the accompanying curve (fig. 12):

Evaporation from soil exposed in trays, moistened with water and normal NaCl solution.

Time (min-utes).	Water evaporated (grams).	
	Water.	NaCl s)-lution.
0	0	0
50	11.5	10
90	20.6	18.8
130	29.6	26
160	32.3	28.5
235	36.2	32.1
295	39.5	35.5

As it was not possible to keep the conditions of evaporation constant, the time intervals serve only as an indication of the rate at which the
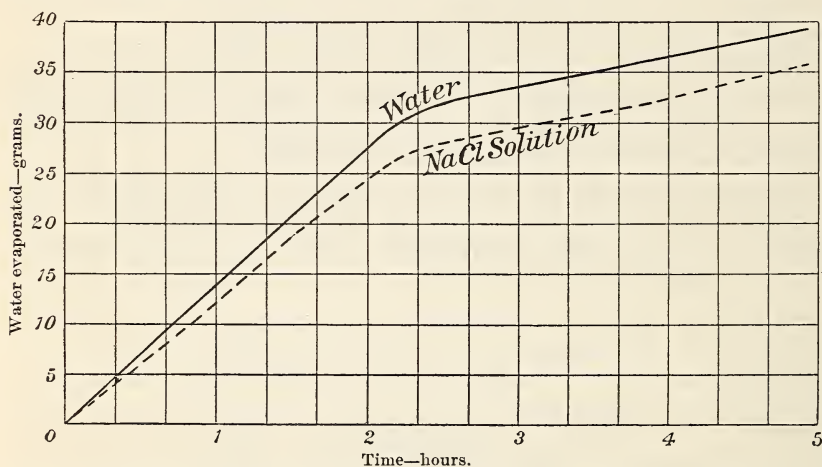

FIG. 12.—Diagram showing evaporation from soil in trays, moistened with water and NaCl solution.

evaporation was taking place. The drying was carried on in a room at a temperature of about 25° C., the air above the trays being kept constantly in motion by means of a fan, and the trays being frequently interchanged to prevent an error due to their position.

It is seen in the table that the rate of evaporation was about 10 per cent greater from the soil moistened with distilled water. It should be remembered that the concentration of the solution in the soil containing the salt constantly increases as the evaporation goes on, and on this account the evaporation should gradually decrease. The actual concentration of the solution in the soil is a matter of more or less conjecture, since the measurements of the electrical conductivity of a soil moistened with salt solution indicate that an appreciable amount of the salt originally added in the form of solution does not remain in solution in the presence of the soil grains. The conductivity of a solution is at least very materially lowered by the addition of the soil, indicating that

physical absorption has taken place and that part of the ions of the salt are no longer free to move.

Experiment 2.—To determine whether the difference in the evaporation observed in Experiment 1 was more than could be accounted for by the difference in the physical properties of the salt solution and pure water, an experiment was conducted to determine the difference in the rate of the evaporation of the two solutions. One hundred grams of distilled water and of a normal solution of sodium chlorid were placed in two Petri dishes $3\frac{3}{8}$ inches in diameter and five-eighths of an inch deep. These dishes were so placed as to be subjected to the same conditions, although no attempt was made to keep these conditions constant. The rate of evaporation is shown in the accompanying table:

Table of evaporation from Petri dishes

Time.	Distilled water, total loss.	NaCl solution, total loss.
Hours.	*Grams.*	*Grams.*
$1\frac{5}{6}$	.9	.9
$4\frac{2}{3}$	2	2
$23\frac{2}{3}$	12.8	11.8
$27\frac{1}{6}$	15.3	14.3
30	18.3	17.1
$49\frac{5}{12}$	35.3	32.3
$53\frac{2}{3}$	41	37.7
$95\frac{3}{4}$	63.5	58.1
$121\frac{1}{12}$	74.3	66.8
$143\frac{2}{3}$	82.6	73.3

From this table it will be seen that the relative rate of evaporation of the distilled water and the salt solution was not sensibly different when freely exposed in evaporating dishes than when mixed with the soil. From this we are justified in concluding that the evaporation of water from the salt solution is not necessarily modified to any appreciable extent by having this solution in contact with the soil grains. In other words, the evaporation of the water from a soil would be modified only by the presence of soluble salts so far as these soluble salts would influence the evaporation of a solution of similar concentration when freely exposed to the air. This

FIG. 13.—Diagram showing evaporation from Petri dishes, distilled water, and normal sodium chlorid solution.

would not amount, as we have seen, even in the case of normal solutions, to more than 10 per cent. This is far from sufficient to explain the great difference noted by Buffum.
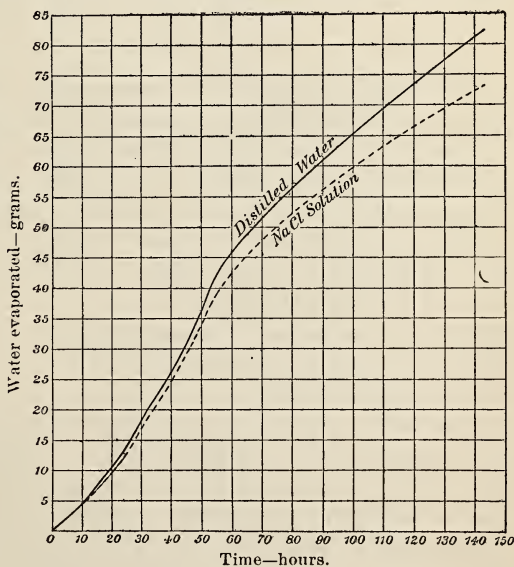
Experiment 3.—It remained to test the opinion of the writer—that the results obtained by Buffum were due to the formation of the crust at the surface of the soil. Accordingly two cylinders 2 inches in diameter and 11 inches high, holding 800 grams of soil, were filled with samples of soil moistened with 20 per cent of distilled water and with normal sodium chlorid, respectively.

To supplement these, a third cylinder of the same dimensions was filled with a soil containing 20 per cent of distilled water to within one-eighth of an inch from the top of the cylinder. The remaining one-eighth inch was filled with pulverized sodium chlorid. These cylinders were kept under similar conditions and the loss of moisture determined by weighing them from time to time. The results are given in the accompanying table:

Table of evaporation from cylinders of soil containing 20 per cent distilled water, 20 per cent normal NaCl, and NaCl on surface.

Time.	Distilled water, total loss.	Normal NaCl solution, total loss.	NaCl on surface, total loss.
Hours.	*Grams.*	*Grams.*	*Grams.*
17	6	0.5	....
24	9	3.5	....
65	19	9	6
120	27	13	10.5
148	32	15.5	13.5
170	38.5	18	15
197	46	21	17.5
222	53	24.5	21.5
245	60	27.5	24
288	70	30.7	28.3
337	81.5	35.5	33.5

The rate of evaporation of water in the three tubes is more clearly shown in the accompanying diagram. The irregularity of the curves is due to the fact that uniform conditions of evaporation could not be maintained. It will be noticed, however, that these irregularities appear in all curves, showing that the tubes were similarly influenced.

From these curves it is evident that the rate of evaporation from the soil containing distilled water was about twice that from the soil moistened with the normal salt solution, confirming in a general way Buffum's experiment. Consequently, we are justified in concluding that for this salt the marked diminution in evaporation is due mainly to surface conditions.

A peculiar condition was noticed in connection with the soil which was moistened with the salt solution. During the evaporation of the water the salt crystallized just beneath the surface of the soil, leaving it in a very loose and porous condition; in fact, after the evaporation had proceeded some time, the surface of the soil in this tube was raised one-half inch or more above the mouth of the tube, due to the formation of minute crystals of the salt interspersed among the soil grains. This tends to confirm the idea that the decreased evaporation in an

alkali soil is due to the formation of a natural mulch, through the crystallization of the soluble salts at the surface, which so loosens the surface as to decrease the evaporation materially.

In the tube in which the soil was covered with a layer of pulverized salt no loosening of the surface was noticed, but the salt seemed to form a solid incrustation over the surface of the soil, reducing the evaporation. The equality in the slope of the two salt curves is important in showing that the influence of the concentration on viscosity and surface tension need not be considered in this case.

SODIUM SULPHATE AND SODIUM CARBONATE.

In order to determine whether the conclusions drawn from the experiments with sodium chlorid applied to all of the more abundant "alkali" salts, experiments similar to those just described were made with sodium sulphate and sodium carbonate by Mr. M. H. Lapham, of this laboratory.

Experiment 1.—This was conducted practically the same as described in the corresponding experiment with sodium chlorid, except that the determinations for each salt were made in duplicate. Four 200-gram samples were exposed in trays, two being moistened with 40 grams of water, and the others with 40 grams of a normal solution of the

FIG. 14.—Diagram showing evaporation from cylinders moistened with distilled water and sodium chlorid solution.

salt under investigation. The results given in the following table are a mean of the duplicate determinations. These are also expressed graphically in figures 15 and 16. It will be noticed that at first the salt has little influence upon the rate of evaporation of the water from the surface of the soil. As the concentration increases and the soil becomes drier the influence of the salt is more marked. In this experiment the greatest diminution in the rate of evaporation produced by the sodium sulphate does not exceed 10 per cent. The experiment with sodium carbonate (figure 16) gave practically the same results.
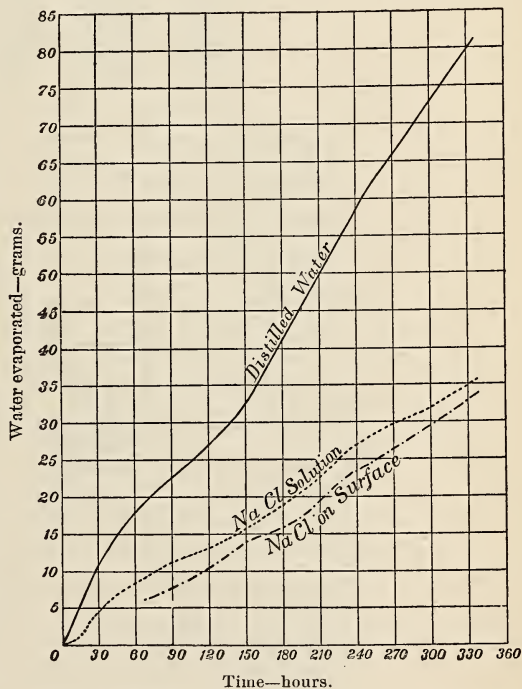
Table of evaporation of distilled water and normal Na_2SO_4 from soil in trays.

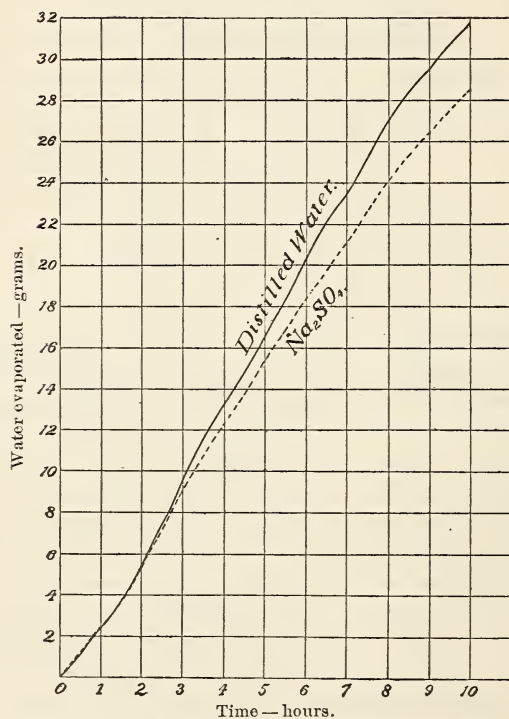| Time.	Distilled water, total loss.	Normal Na_2SO_4, total loss.
Hours.	*Grams.*	*Grams.*
$0\frac{1}{2}$	1	1. 30
1	2. 40	2. 55
$1\frac{1}{2}$	3. 60	3. 65
2	5. 55	5. 60
$2\frac{1}{2}$	7. 50	7. 30
3	9. 70	9. 30
$3\frac{1}{2}$	11. 55	10. 90
4	13. 30	12. 45
$4\frac{1}{2}$	14. 85	13. 85
5	16. 70	15. 55
$5\frac{1}{2}$	18. 40	16. 90
6	20. 30	18. 50
$6\frac{1}{2}$	22. 15	19. 90
7	23. 55	21. 15
$7\frac{1}{2}$	25. 25	22. 75
8	26. 90	24. 25
$8\frac{1}{2}$	28. 20	25. 45
9	29. 45	26. 60
$9\frac{1}{2}$	30. 65	27. 70
10	31. 70	28. 55

FIG. 15.—Diagram showing evaporation from soil in trays moistened with distilled water and sodium sulphate solution.

Table of evaporation of distilled water and normal Na_2CO_3 solution from soil in trays.

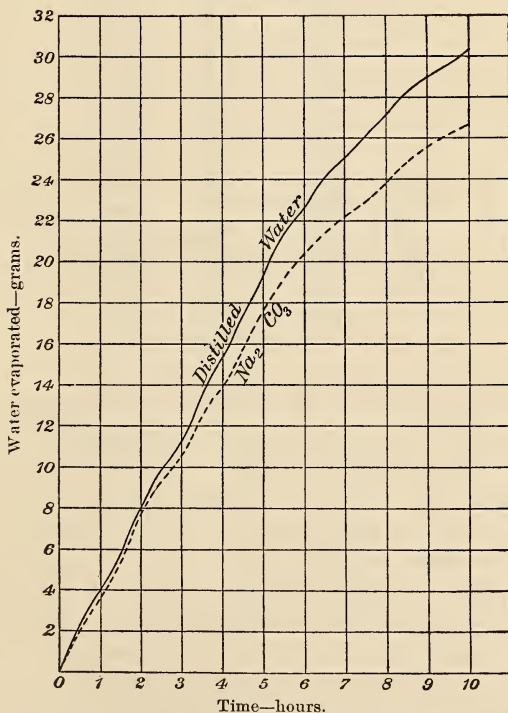| Time.	Distilled water, total loss.	Normal Na_2CO_3, total loss.
Hours.	Grams.	Grams.
0½	2. 25	2. 15
1	3. 95	3. 70
1½	5. 80	5. 35
2	8. 30	7. 80
2½	9. 85	9. 30
3	11. 30	10. 50
3½	13. 50	12. 45
4	15. 30	13. 90
4½	17. 35	15. 75
5	19. 40	17. 65
5½	21. 30	19. 20
6	22. 60	20. 25
6½	24. 05	21. 35
7	25. 05	22. 15
7½	26. 10	22. 95
8	27. 05	23. 90
8½	28. 25	24. 80
9	28. 90	25. 55
9½	29. 55	26. 05
10	30. 30	26. 65

FIG. 16.—Diagram showing evaporation from soil in trays moistened with distilled water and normal sodium carbonate solution.

Experiment 2 A.—These experiments were conducted for the purpose of determining the relative rate of evaporation from the surfaces of pure water and salt solutions under ordinary atmospheric conditions of temperature, pressure, and humidity. The water and the salt solutions were exposed in Petri dishes of the same diameter and depth.

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The air above the dishes was kept gently moving by means of an electric fan, and all precautions to obtain uniform conditions were observed. The results of the experiments are given in the following table and shown graphically in fig. 17:

Table of evaporation of distilled water and normal Na_2SO_4 and Na_2CO_3 solutions from Petri dishes.

Time.	Distilled water, total loss.	Normal Na_2SO_4, total loss.	Normal Na_2CO_3, total loss.
Hours.	*Grams.*	*Grams.*	*Grams.*
1	1.10	1.05	1.10
2	2.20	2.10	2.20
3	3.45	3.20	3.30
4	4.45	4.30	4.40
5	5.15	5.00	5.10
6	6.00	5.80	5.80
7	6.75	6.50	6.60
8	7.50	7.30	7.30
9	8.40	8.20	8.20
10	9.40	9.10	9.20
11	10.35	10.00	10.10
12	11.25	10.80	10.90
13	12.30	11.80	11.85
14	13.35	12.80	12.80
15	14.15	13.60	13.70
16	15.10	14.50	14.60
17	15.90	15.20	15.30
18	16.75	16.00	16.20
19	17.60	16.90	17.00
20	18.15	17.40	17.50
21	18.80	18.00	18.20
22	19.50	18.80	18.90
23	20.25	19.40	19.50
24	21.05	20.20	20.30
25	21.60	20.70	20.90
26	22.40	21.40	21.60
27	22.95	22.00	22.20
28	23.50	22.50	22.70
29	24.10	23.00	23.20
30	24.65	23.50	23.70
31	25.25	24.00	24.30
32	25.95	24.60	24.90
33	26.50	25.10	25.50
34	27.10	25.60	25.90

The evaporation curves for the solutions are displaced to the right to avoid confusion. The concentration beginning with normal solution increases with evaporation until a saturated solution of sodium sulphate is obtained. The three solutions, however, show very little difference. The sodium carbonate solution evaporated a little more rapidly than the other, probably due to the fact that it does not dissociate so strongly as sodium sulphate, and hence has a higher vapor pressure. Neither of these solutions show anything like the diminution in the rate of evaporation which we should expect from theoretical considerations of the lowering of the vapor pressure due to the concentration. Consequently, we are led to conclude that the rate of the diffusion of the water vapor under ordinary conditions is the controlling factor, and that the concentration of the solution would play the more important part only when the surface of the solution is continually being supplied with vapor-free air.

Experiment 2 B.—In order to substantiate more completely the conclusion that the evaporation from reservoir or soil is not diminished by

the presence of salt in solution to the extent which consideration of the lowering of the vapor pressure would lead us to assume, a determination was made of the relative rate of evaporation of water and of saturated solutions of the three salts previously used. The solutions were exposed in Petri dishes as before, while the surfaces of the liquids were constantly swept by a strong blast of air from an electric buzz fan. The blast of air was sufficiently strong to produce pronounced ripples on the surfaces of the liquids, particularly that of the distilled water, the increased viscosity of the solutions somewhat diminishing this effect. Therefore, the conditions of this experiment—the rapid movement of air over saturated solutions— are such as to give the maximum influence of the salts investigated on the

FIG. 17.—Diagram showing evaporation from Petri dishes, normal solutions.

diminution of evaporation under the given conditions of temperature and pressure. The results are shown in the following table and curve, fig. 18:
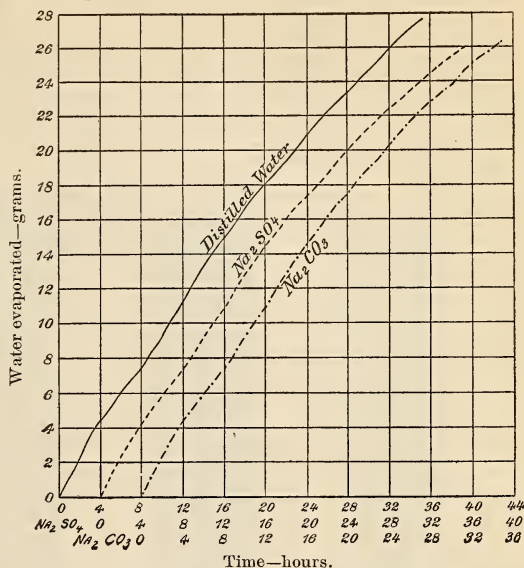
Table of evaporation of distilled water and saturated solutions of NaCl, Na₂SO₄ and Na₂CO₃ from Petri dishes.

Time.	Dist. water, total loss.	NaCl, total loss.	Na$_2$SO$_4$, total loss.	Na$_2$CO$_3$, total loss.
Hours.	*Grams.*	*Grams.*	*Grams.*	*Grams.*
½	1	0.8	0.9	1
1	2.3	1.8	2.1	2.3
1½	4.2	3.5	4.0	3.9
2	5.6	4.7	5.5	5.3
2½	7.8	6.4	7.5	7.3
3	9.7	8	9.4	9
3½	11.1	9.3	10.7	10.2
4	12.9	11	12.6	11.8
4½	14.8	12.6	14.3	13.2
5	16.5	14.2	15.9	14.4
5½	17.8	15.2	17.3	15.5
6	19.1	16.4	18.6	Crystallized
6½	20.5	17.6	19.9	....
7	....	Crystallized.		....

These results show a maximum diminution in the rate of evaporation of about 14 per cent. The average temperature of the laboratory was 19° C., while the average relative humidity was 45 per cent. An average of 15 grams of water was evaporated from each dish during six hours. Since the diameter of the dish was about 8.4 cm., this would correspond to an evaporation of 1.1 cm. per square centimeter of surface or 0.44 inch per square inch during twenty-four hours. The humidity and rate of evaporation are consequently such as to make the results of this experiment applicable to arid conditions.

Experiment 3.—This experiment was conducted similar to that for sodium chlorid. Three cylinders were filled with soil moistened with
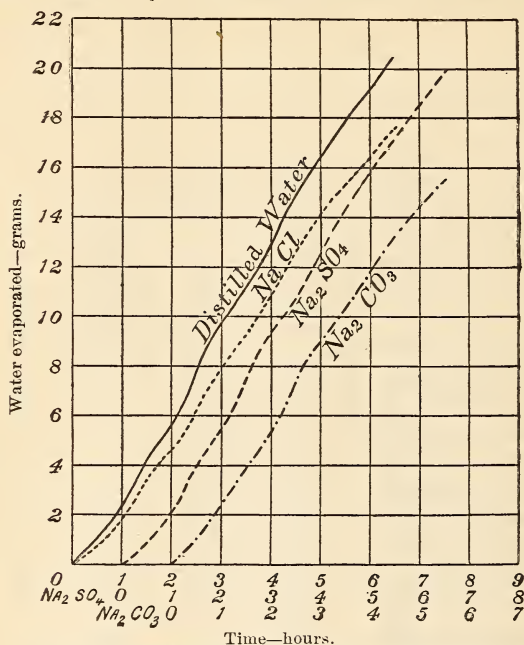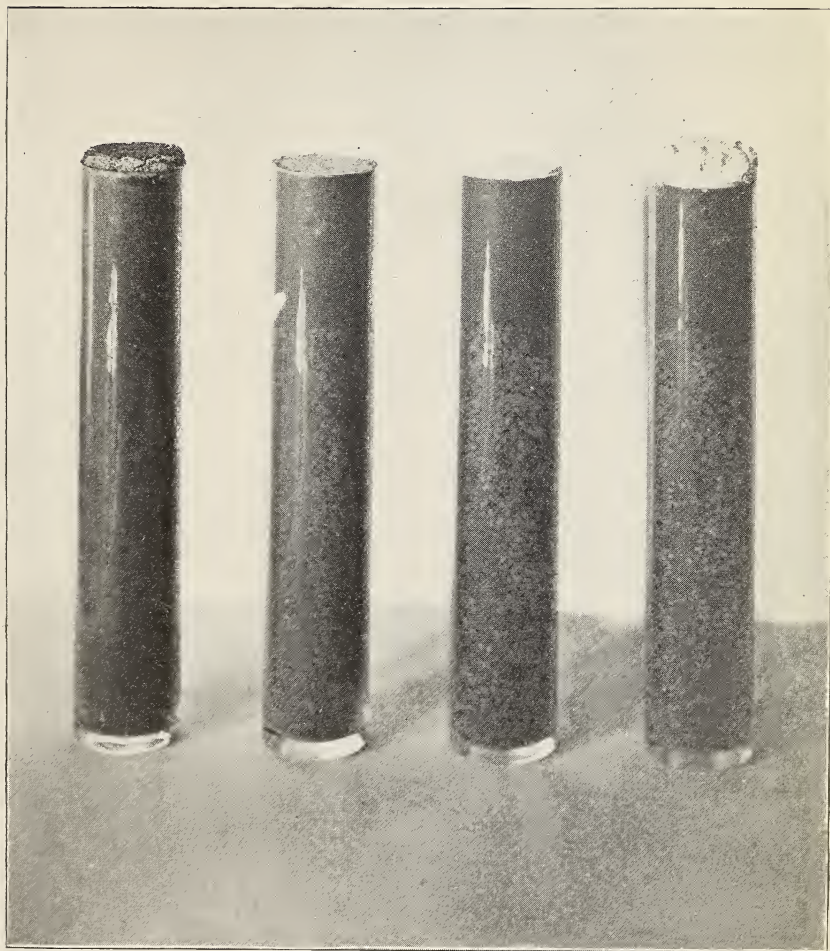

FIG. 18.—Diagram showing evaporation from Petri dishes, saturated solutions.

20 per cent by weight of distilled water and normal solutions of sodium sulhpate and sodium carbonate, respectively. In a fourth cylinder the soil was moistened with distilled water and mulched with a layer of sodium sulphate one-eighth inch thick. The results are shown in the accompanying table and curves, fig. 19:

Table showing evaporation from soil cylinders—Distilled water, normal Na₂ CO₃ and Na₂ SO₄ solutions, and Na₂ SO₄ mulch.

Time in days.	Distilled water.	Normal Na₂ CO₃.	Normal Na₂ SO₄.	Distilled water with Na₂ SO₄ as mulch.
	Total loss in grams.	*Total loss in grams.*	*Total loss in grams.*	*Total loss in grams.*
¼	2.5	1.9	1.6	1.2
1	8.4	5.8	5.5	4.2
1¼	11.2	7.2	7.1	5.6
2	17.6	11.0	11.4	9.4
2¼	19.8	12.1	12.7	10.6
3	26.1	15.3	16.6	14.4
3¼	28.2	16.4	17.9	15.7
4	34.4	19.2	21.8	19.4
4¼	36.2	19.9	22.8	20.6
5	43.4	23.0	26.9	24.7
5¼	45.3	23.8	28.0	26.0
6	50.9	26.4	31.8	30.0
6¼	52.6	27.0	32.9	31.2
7	57.6	29.3	36.3	34.7
7¼	58.9	29.8	37.1	35.6
8	62.7	31.5	39.5	38.2
8¼	64.2	32.1	40.5	39.2
9	69.3	34.1	43.5	42.7
9¼	70.7	34.5	44.2	43.7
10	75.2	36.3	47.1	46.8

PLATE XXIX.

EVAPORATION CYLINDERS.

These experiments also corroborate those of Buffum, the evaporation from the cylinders containing salt being only from 50 per cent to 60 per cent of that from the cylinder moistened with distilled water. This diminution in evaporation is, as we have seen, much greater than can be explained through the physical properties of solutions of these salts. Consequently this must be due to the formation of a mulch on the surface of the soil, resulting from the crystallization of the salt on evaporation. This is well exemplified in Plate XXIX, which represents the condition of the tubes at the close of the experiment. The loose white efflorescence on the surace of the sodium sulphate soil is very marked. The accumulation of salt in the sodium carbonate tube is much less marked, on account of the remarkable degree to which this salt is absorbed by the soil and kept from accumulating at the surface. The crystallizing out of the soil at the surface does take place to some extent, but the white crystals are masked by the accompanying organic matter which this salt brings into solution. The resultant dark color of the surface, which so characterizes the presence of this salt in alkali soils, was very marked in the sodium carbonate tube during the first part of the experiment. This is shown to some extent in Plate XXIX. The tube containing the sodium sulphate as a mulch does
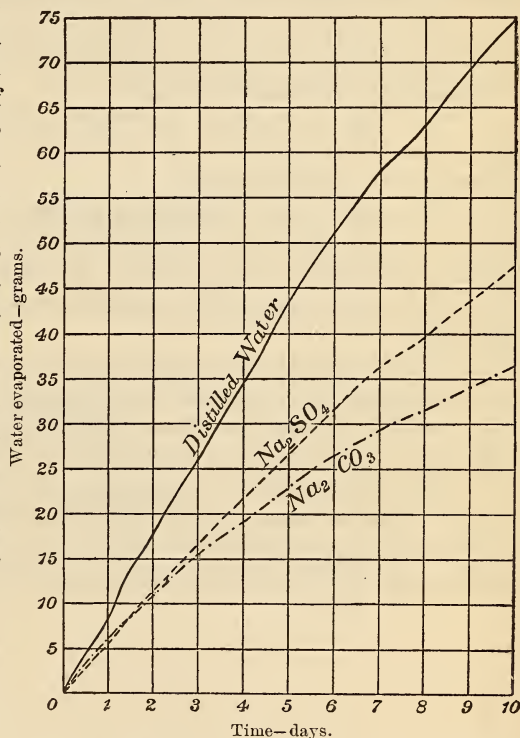

Fig. 19.—Diagram showing evaporation from cylinders of soil moistened with distilled water and with normal sodium carbonate and sodium sulphate solutions.

not differ materially in its rate of evaporation from the tubes containing the solutions, showing that the conditions within the soil are secondary to surface conditions in alkali soils.

Sodium carbonate does not form at the surface the loose, fluffy mixture of soil grains and salt crystals so characteristic of sodium sulphate and sodium chlorid, but tends rather to the formation of a crust which is more or less broken and tilted by the subsequent crystallization beneath. This action, of course, depends upon the texture of the soil, and in field conditions this would be influenced by the presence of other salts.

CONCLUSIONS.

From the results given in the paper the following conclusions may be drawn:

(1) Salts influence the evaporation of water from the surface of a soil by changing the surface tension, the viscosity and the vapor pressure of the system, and the physical character of the soil, particularly at the surface.

(2) The surface tension and viscosity influence the rate of evaporation only through the modification of the rate of capillary movement. Both surface tension and viscosity increase with increase in concentration. An increase in surface tension increases the rate of capillary movement, while increase in viscosity diminishes it. These two factors, consequently, oppose one another.

(3) The rate of capillary movement within a soil is of secondary importance to the physical character of the surface, as modified by the presence of crystallized salts.

(4) The relative rate of evaporation from a soil moistened with pure water and salt solution, respectively, is the same as for the water and solution without the soil, providing no surface mulch is formed.

(5) The rate of evaporation gradually decreases with increase in concentration.

(6) The diminution of evaporation with increasing concentration is much less than the corresponding diminution in vapor pressure. This is due to the fact that the atmosphere is never vapor-free and that the diffusion of water vapor is retarded by the surrounding air.

(7) The diminution of evaporation of soils containing solutions of "alkali" salts is much greater than can be accounted for through the influence of the lower vapor pressure, and is due to the formation of a mulch at the surface of the soil through the crystallization of the salts.

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